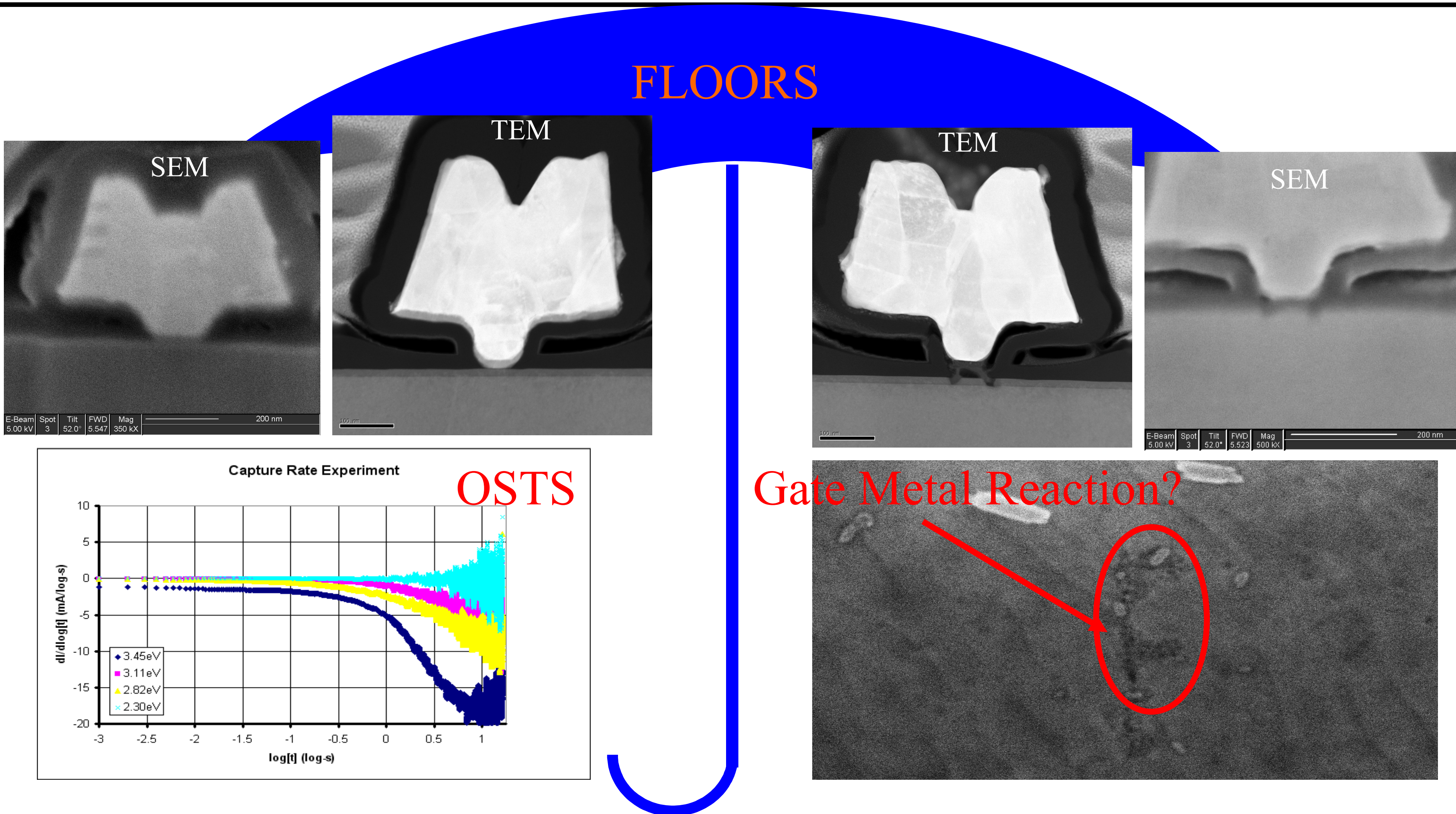
Deprocessing and defect analysis of GaN/AlGaN HEMTs

Patrick Whiting, Ray Holzworth

Dr. Nicholas Rudawski, and Dr. Kevin Jones

GATOR Engineering
UNIVERSITY OF FLORIDA

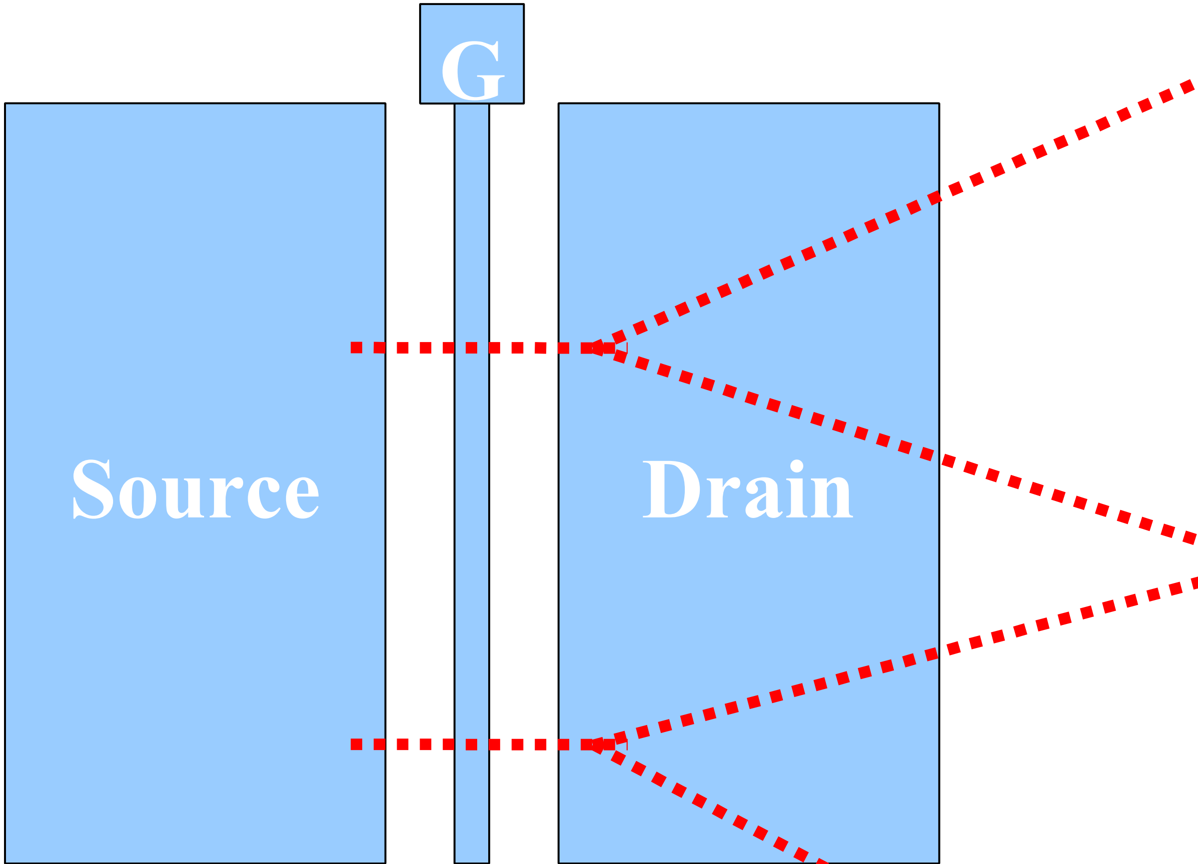
Scientific Approach

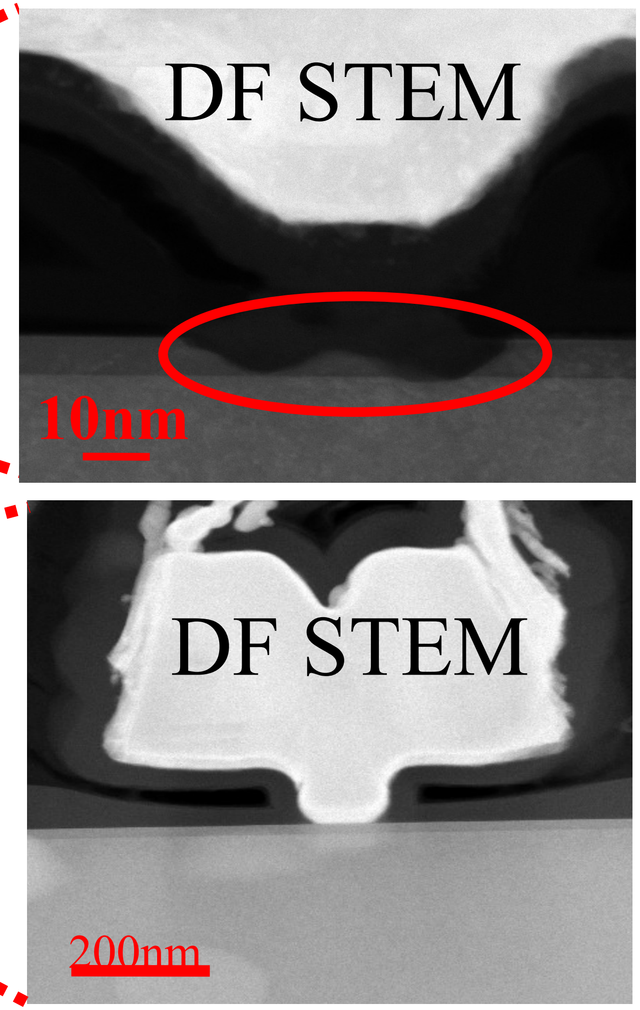


t=0, As Built

t>0, Degradation

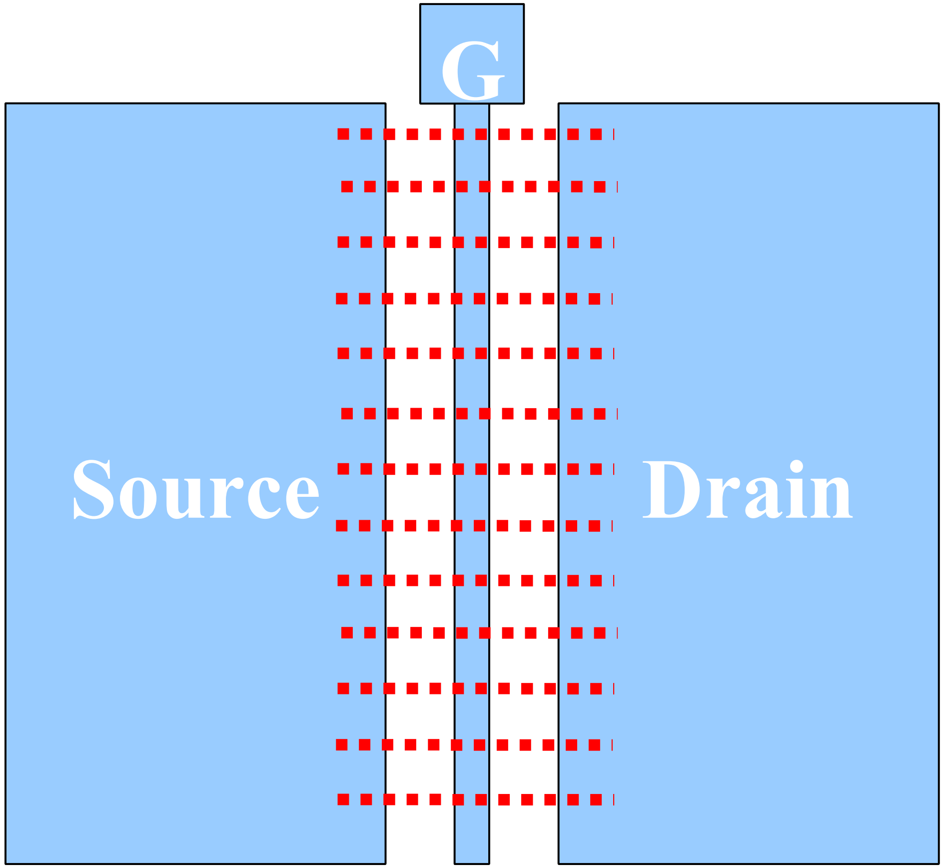
Motivation





Defect density varies along the length of HEMT devices. Formation is a stochastic process.

Motivation



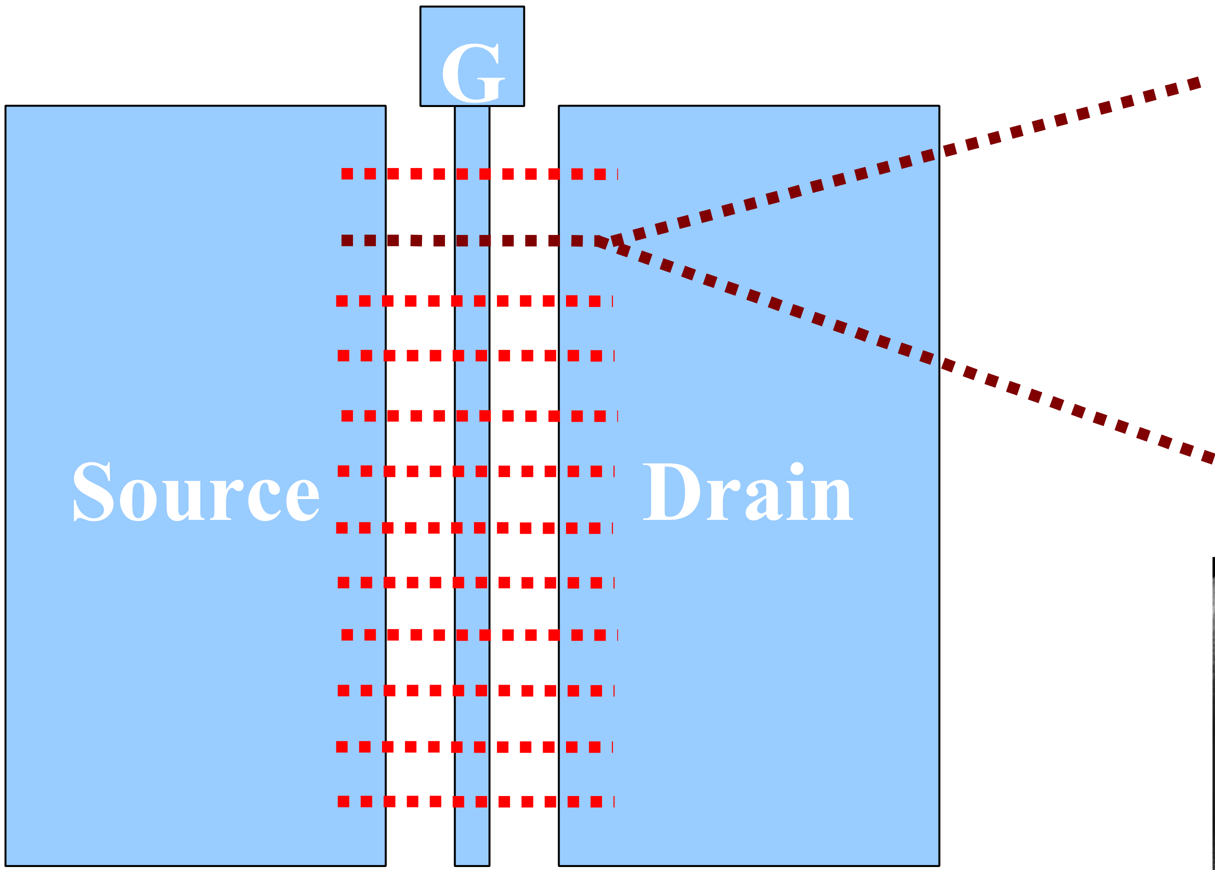
150um Gate / 5um per TEM crosssection
= 30 TEM cross-sections

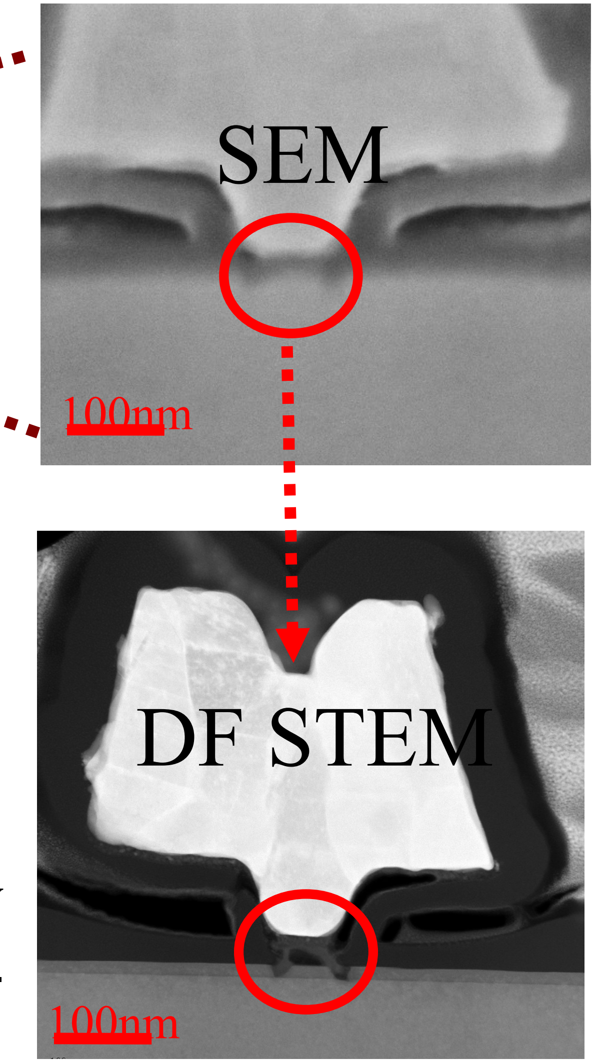
40 TEM cross-sections * 1 hr per section
= 30 hours of FIB time
= $2,100 per device

40 TEM cross-sections* .5 hr per section
= 15 hours of TEM time
= $1,050 per device

One solution is to determine defective quality by looking at lots of cross-sections. This is expensive!

Motivation

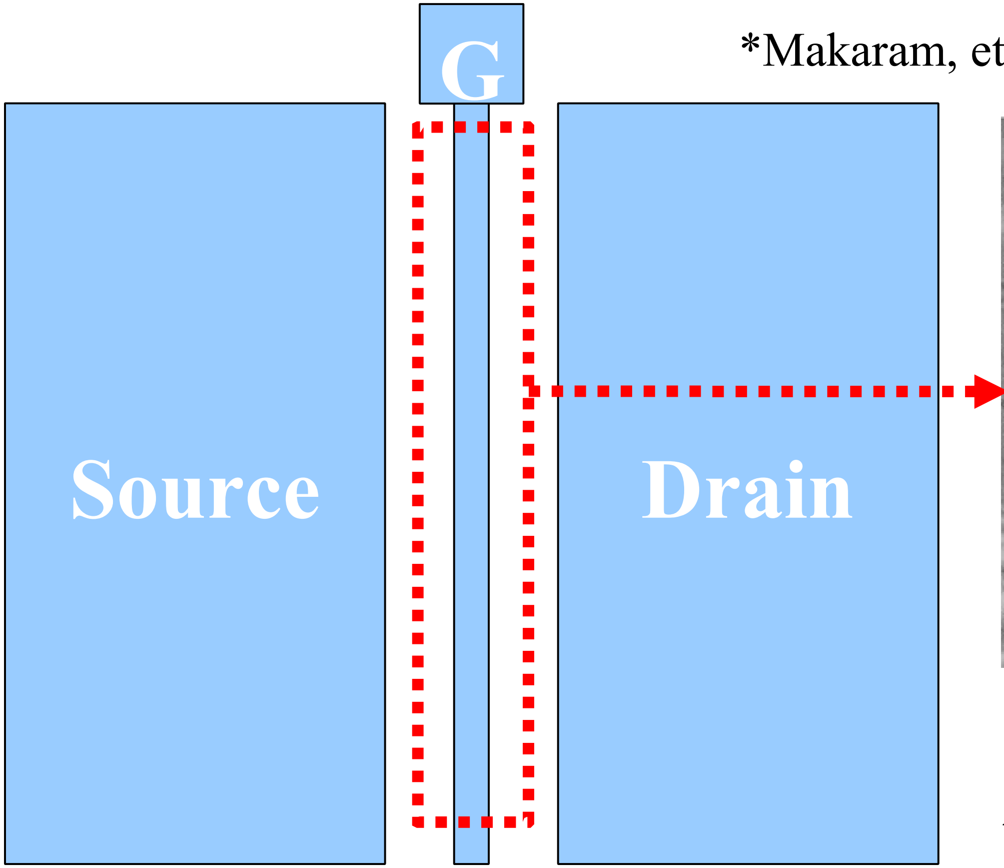


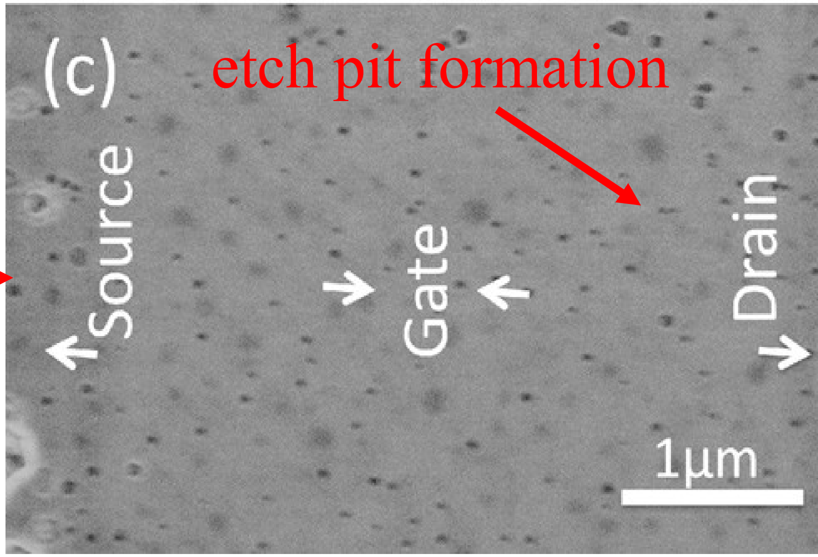


Another option is to use the Slice and View method to reduce the number of TEM cross-sections. Resolution suffers, however.

Motivation

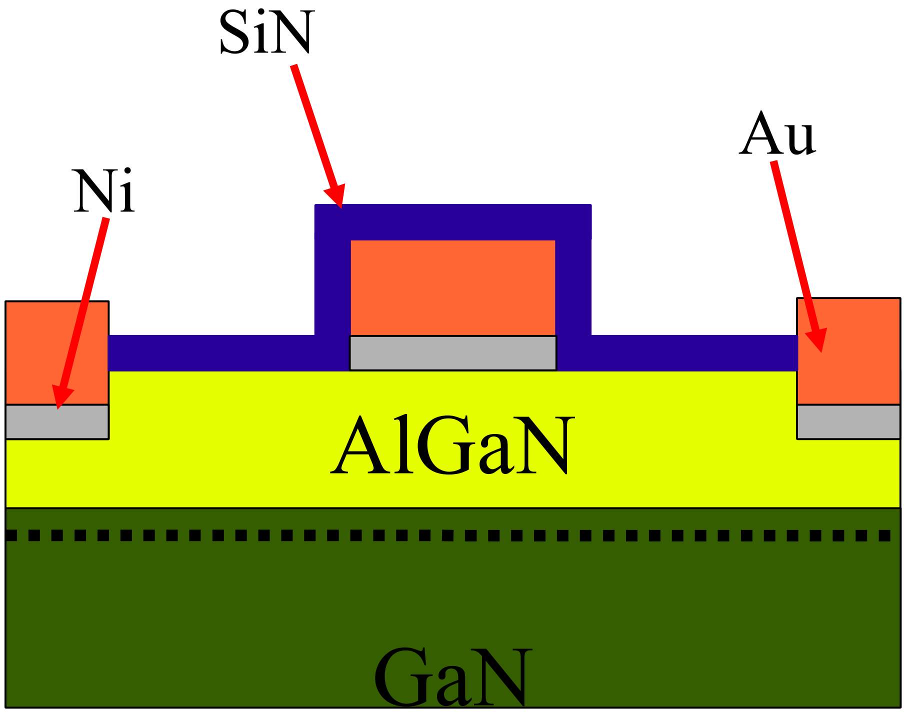
*Makaram, et. al., Applied Physics Letters **96**, 23 (2010)

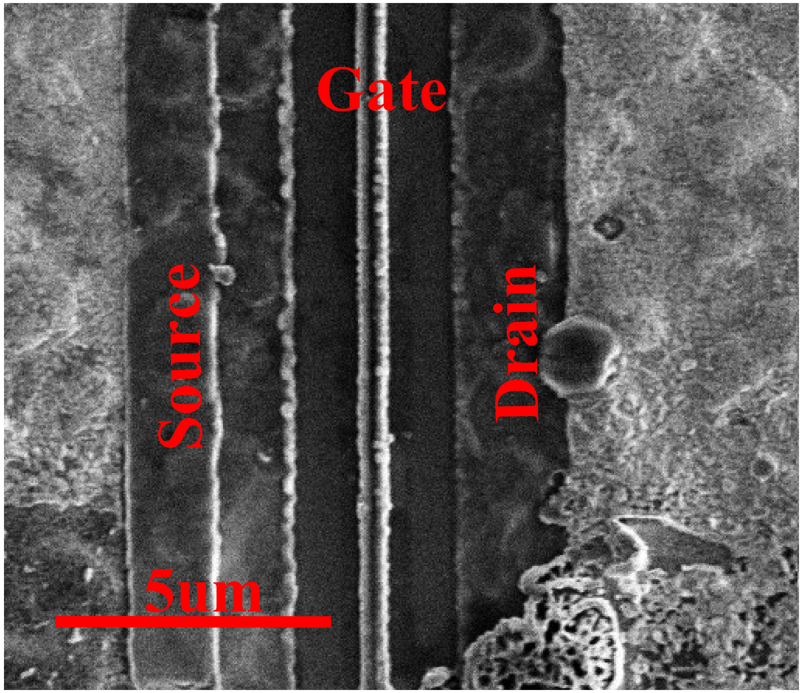




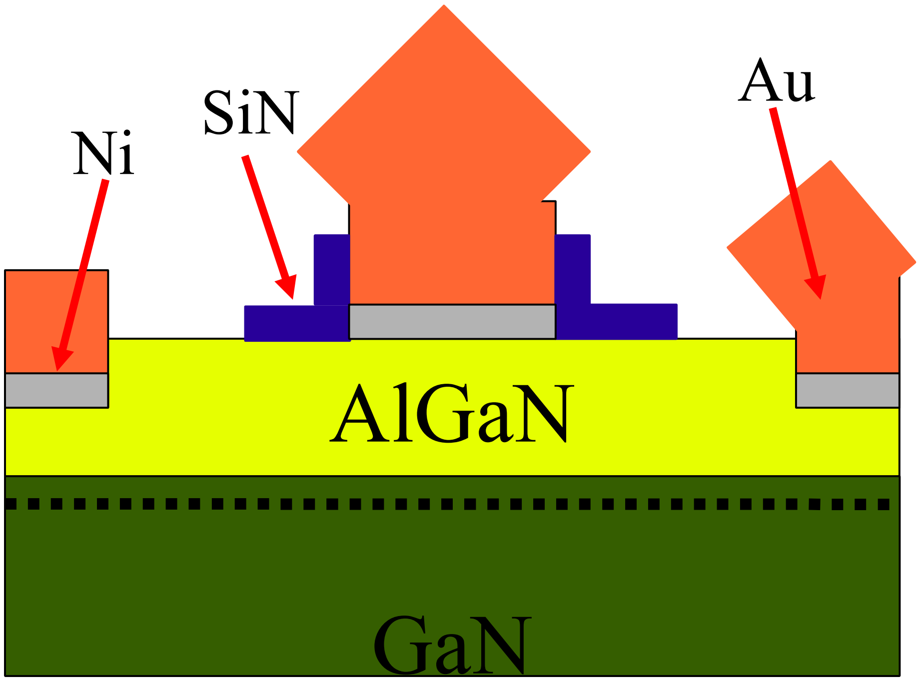
The simplest (and arguably, the best) option is to deprocess the sample and perform Plan-View SEM.*

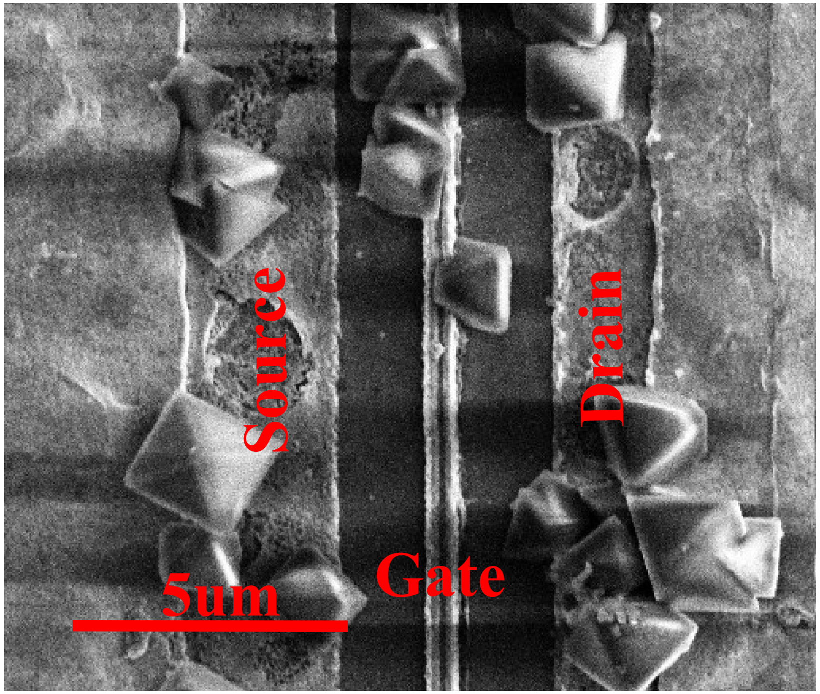
Deprocessing: Initial Conditions





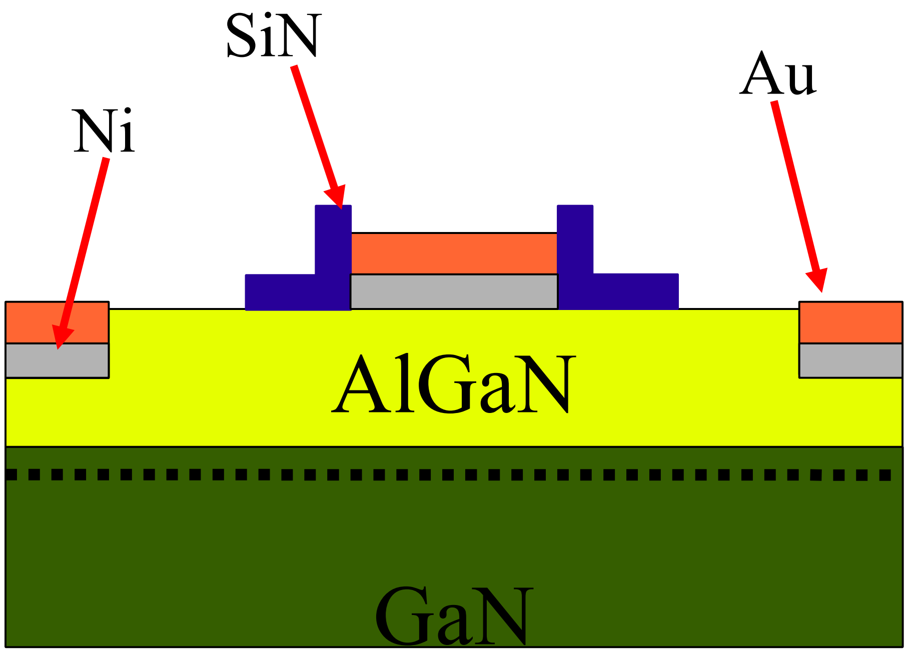
Deprocessing: Nitride Strip

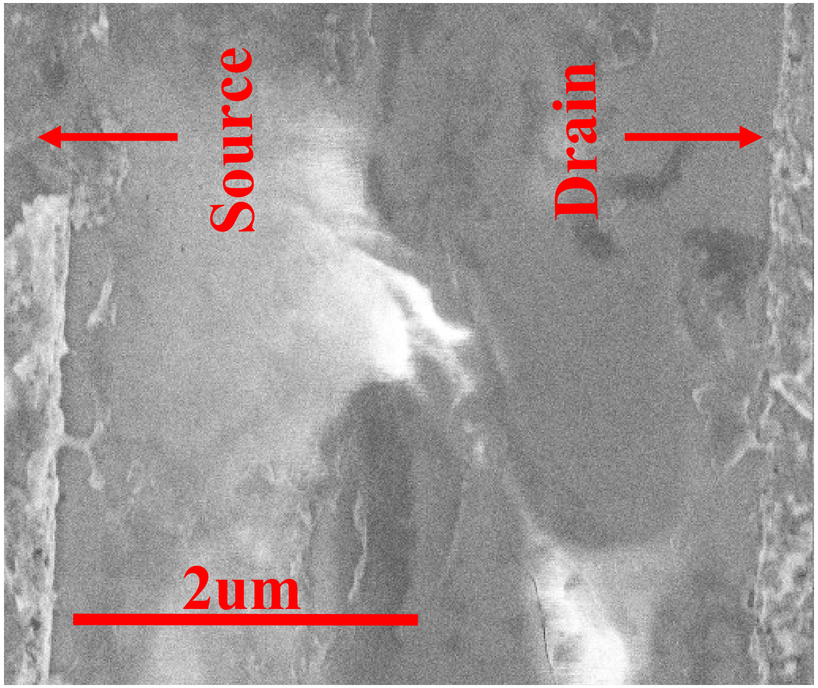




- 6:1 $HF:NH_3F$ Bath for 9 minutes

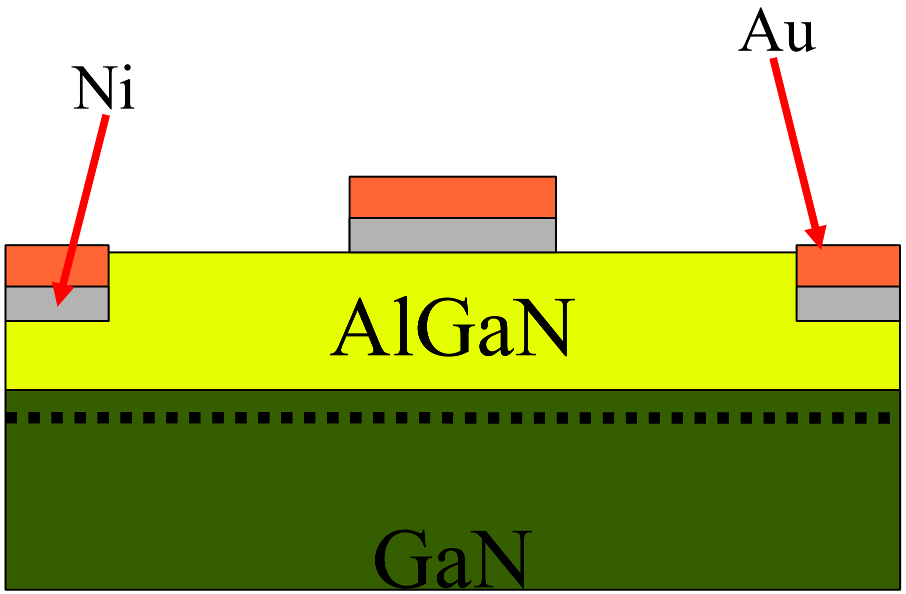
Deprocessing: Gold Precipitate Clean

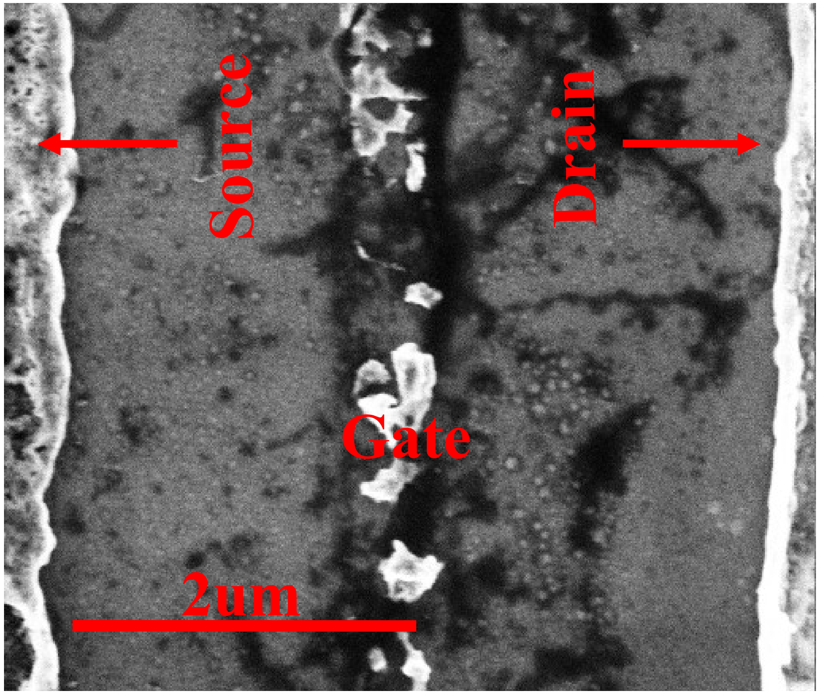




- TFAC (FeCN/KCN solution) bath for 20 minutes
- TFAC Gold Etchant produced by Transene Corp.

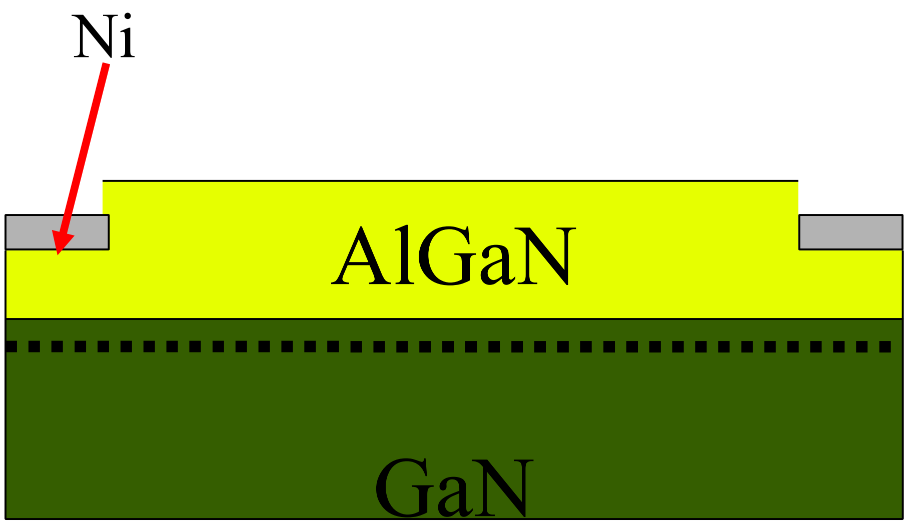
Deprocessing: Second Nitride Strip

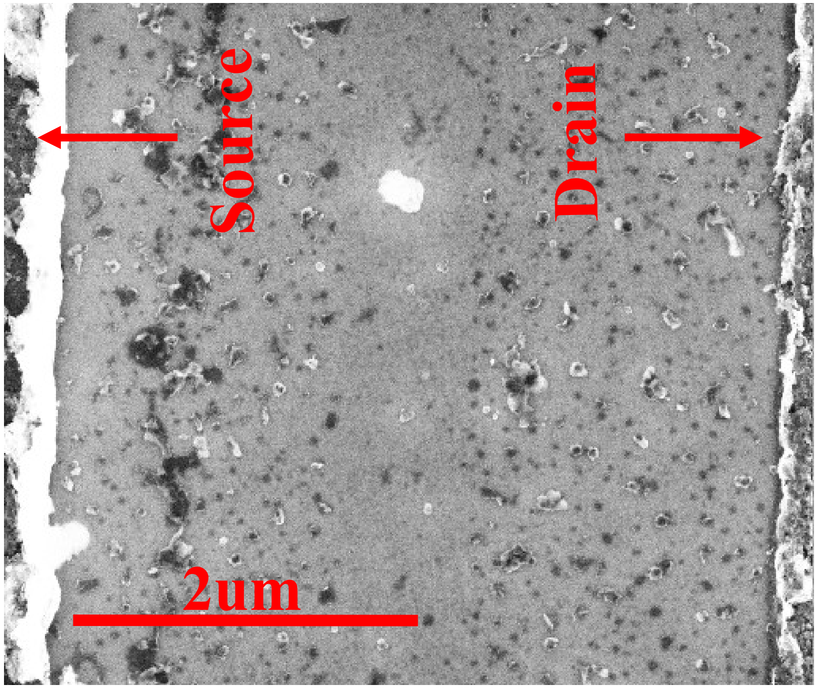




- 6:1 HF:NH_3F Bath for 6 minutes

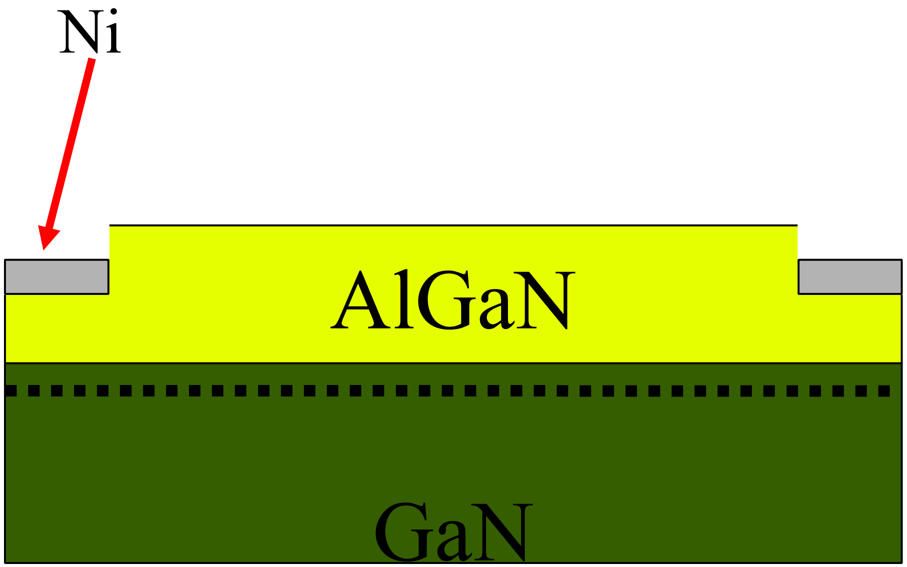
Deprocessing: Metal Strip

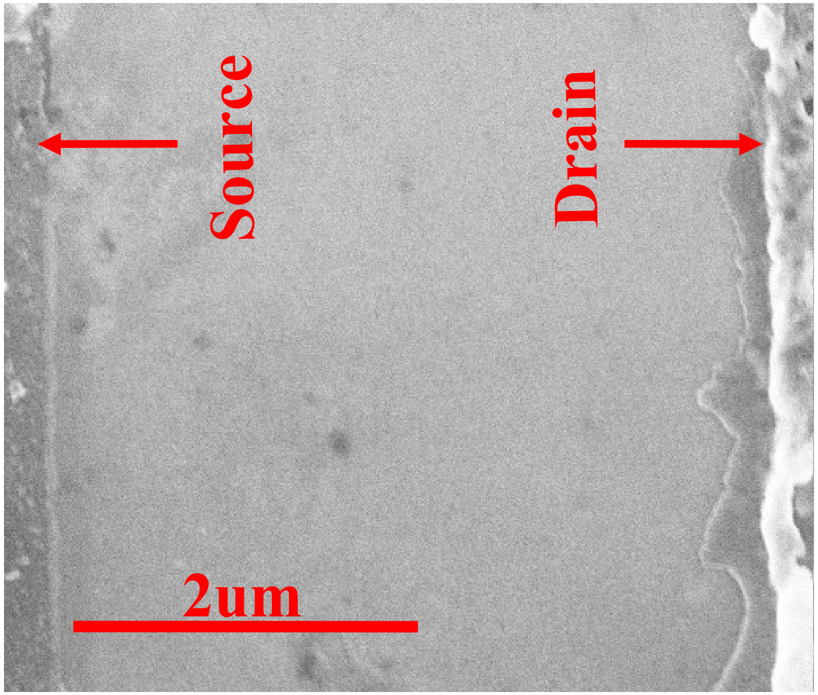




- TFAC (FeCN/KCN solution) bath for 3 hours
- TFAC Gold Etchant produced by Transene Corp.

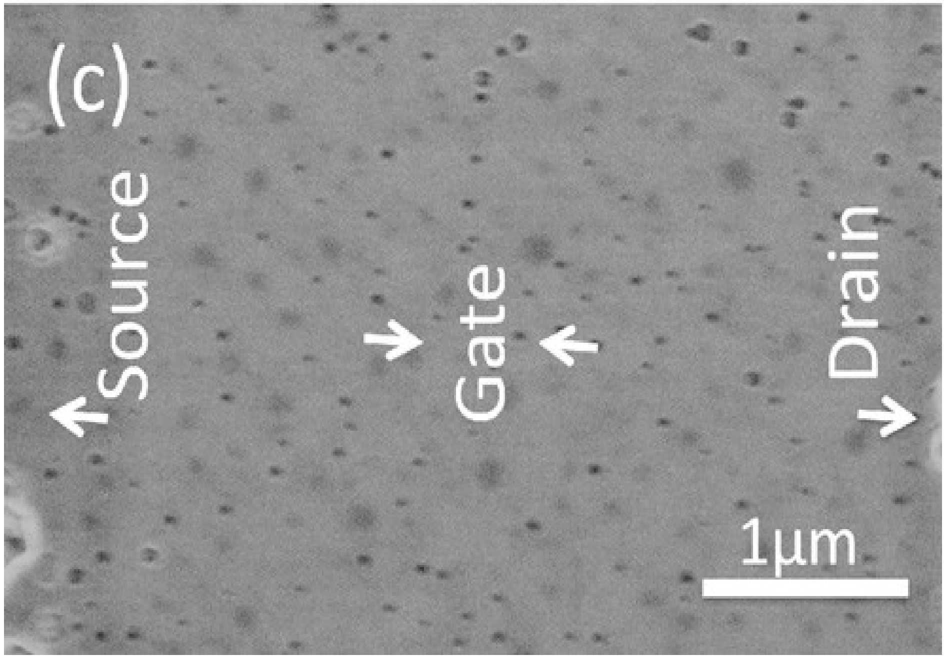
Deprocessing: Ultrasonic Clean

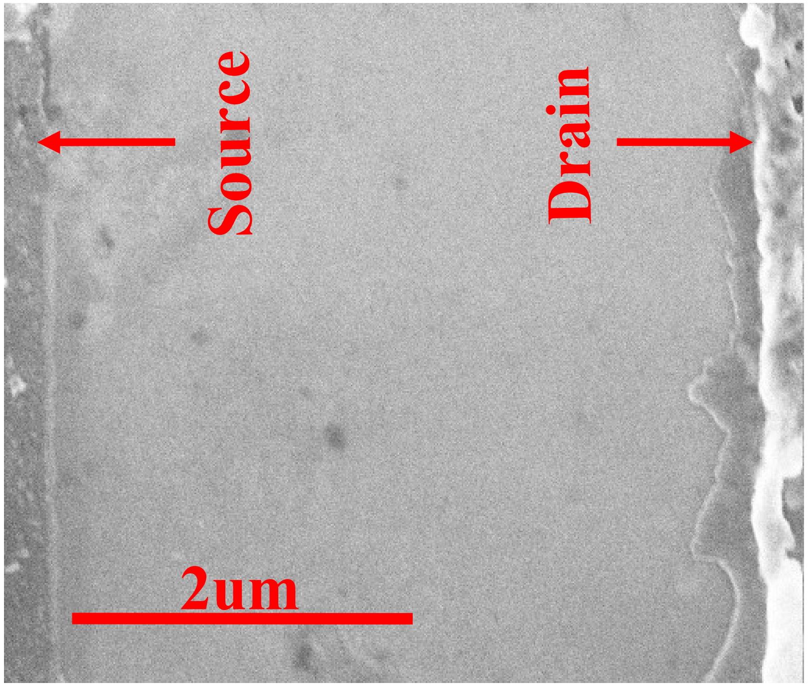




- 6:1 HF:NH_3F Bath for 3 minutes
- Ultrasonic Methanol bath for 20 minutes

Comparison: delAlamo Group (MIT)

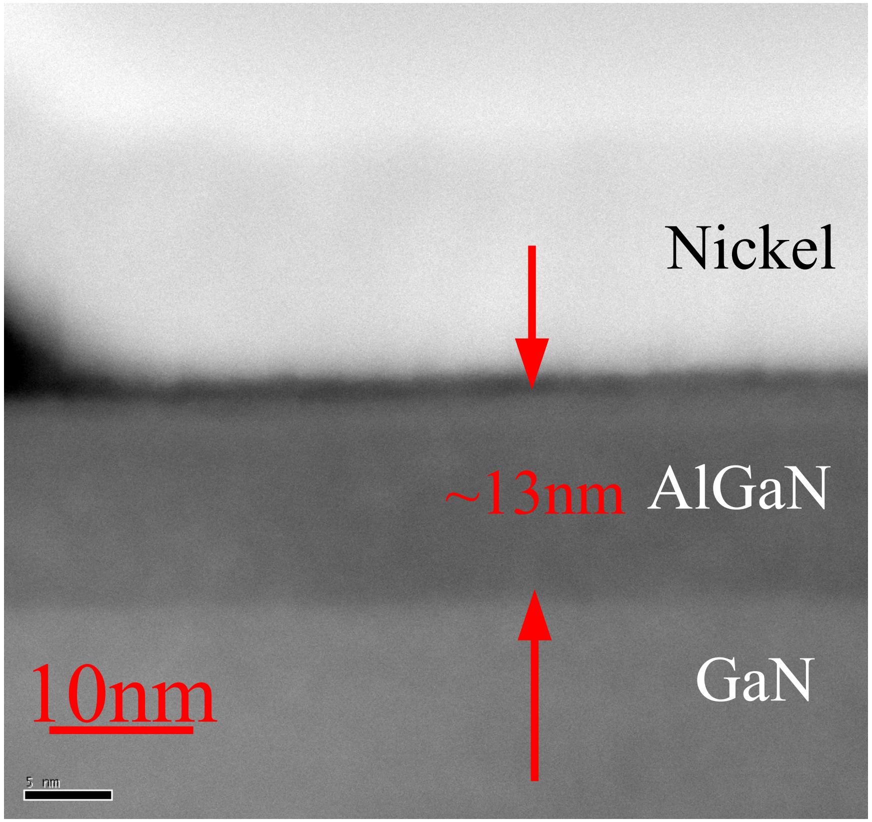




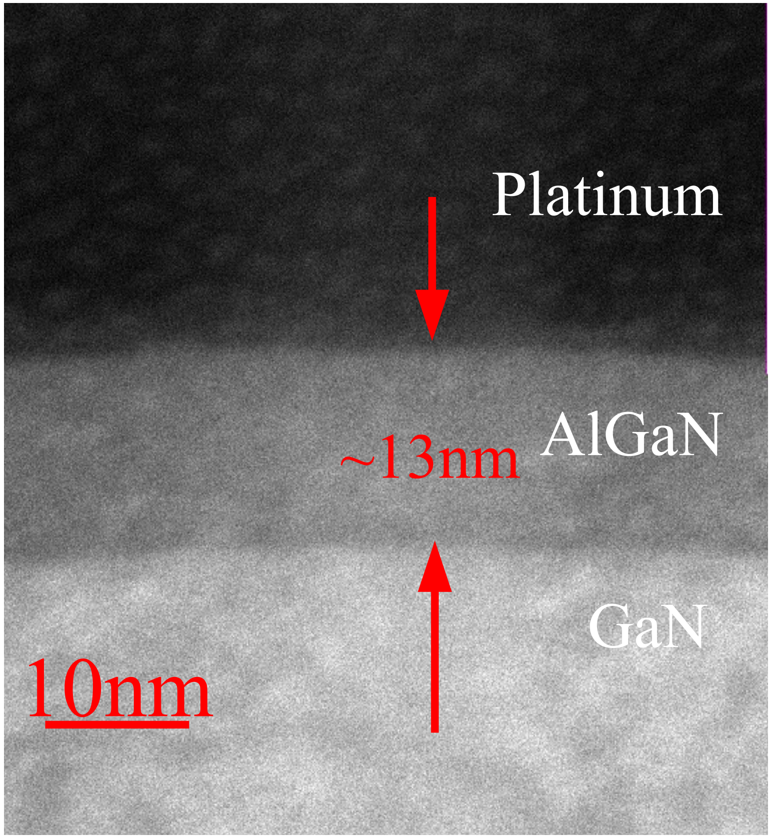
- Left: BOE Nitride Strip with Aqua Regia Metal Etch (MIT)
- Right: BOE Nitride Strip with FeCN/KCN (UF)

Selectivity

The process does not appear to attack AlGaN



Control

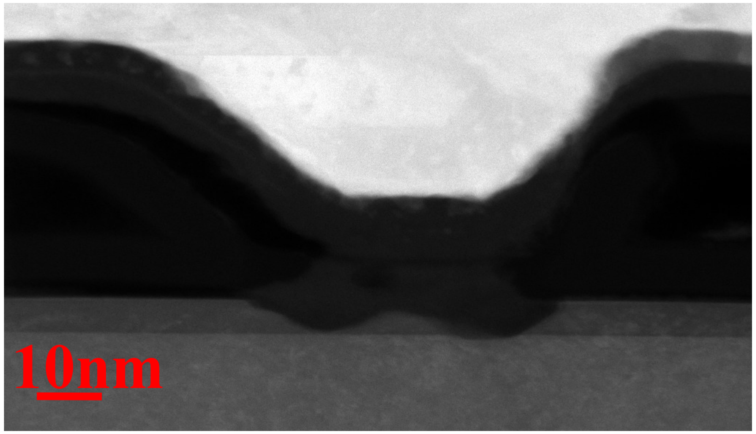


Post-Etch Sample

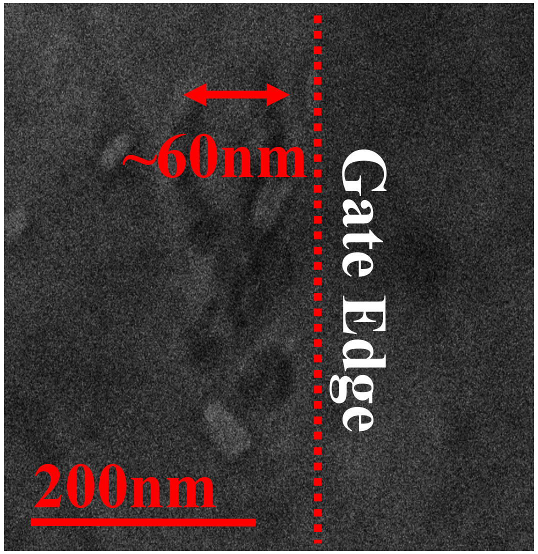
Analysis of AFRL1813

Presence of reaction-based defect?

AFRL1813Plan-View SEM



AFRL1813: DF STEM



AFRL1813 Plan-View SEM

Conclusions

- Slice-and-View SEM and TEM analysis may not be the best way to perform statistical analysis of gate electrode defects.
- A new technique for deprocessing the channel regions of stressed devices has been developed.
- This new technique was used in the analysis of a previously stressed device. SEM analysis indicates that the technique shows promise as a means of viewing defects in plan-view.

Future Work

- Development of complementary AFM technique for characterization of the denuded channel regions.

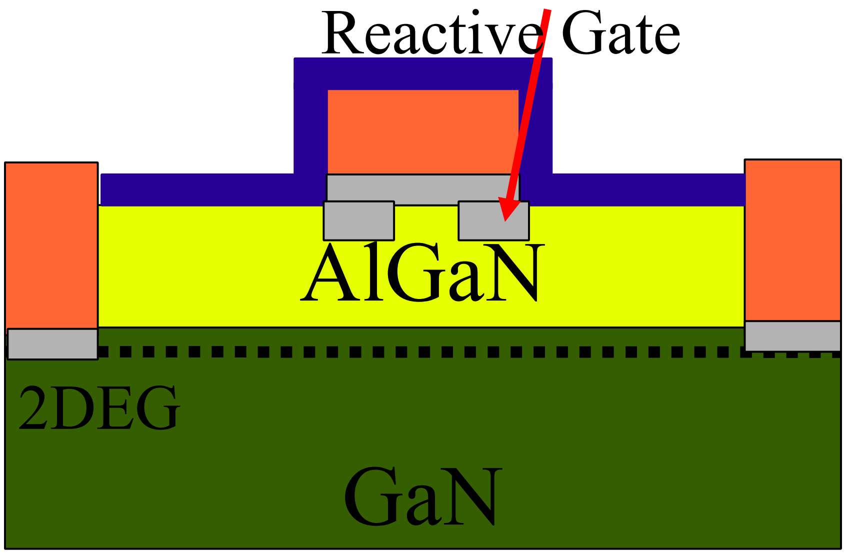
- Combination of the deprocessing technique outlined above with AFM/SEM to investigate HEMT structures bias-stressed for longer time periods.

A System for the Characterization of Electronic Defects in AlGaN/GaN HEMTs

Patrick Whiting, David Cheney and Erica Douglas
Dr. Brent Gila, Dr. Kevin Jones, Dr. Stephen Pearton

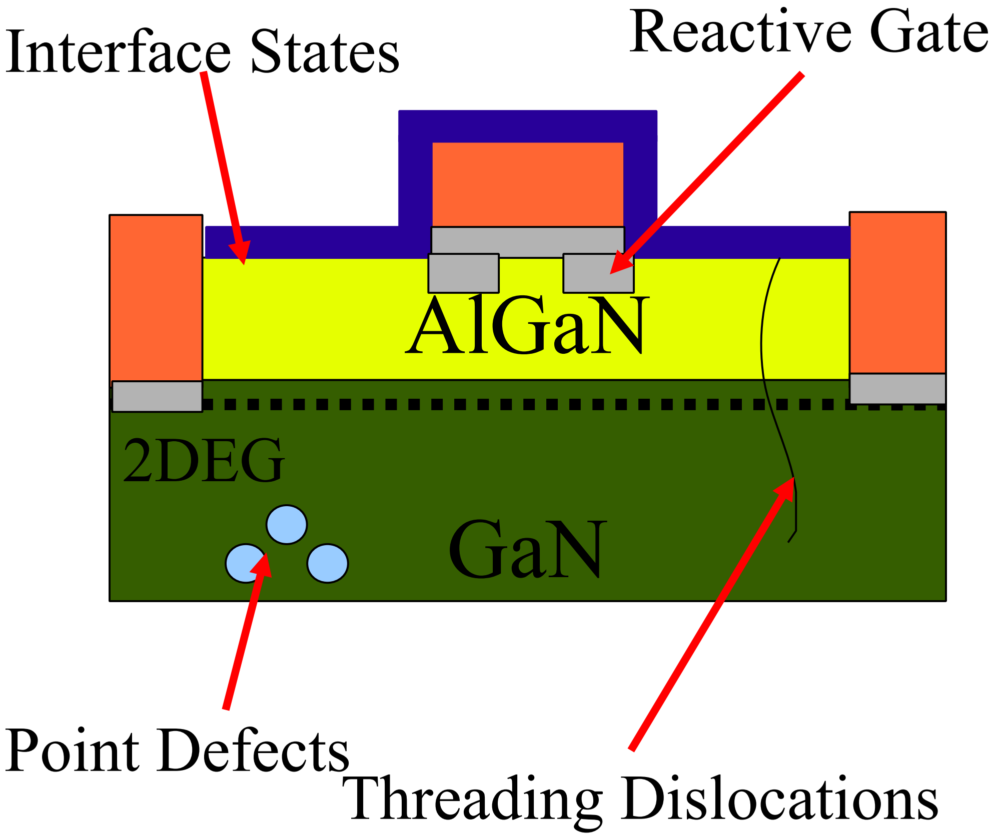
GATOR Engineering
UNIVERSITY OF FLORIDA

Where can traps come from?



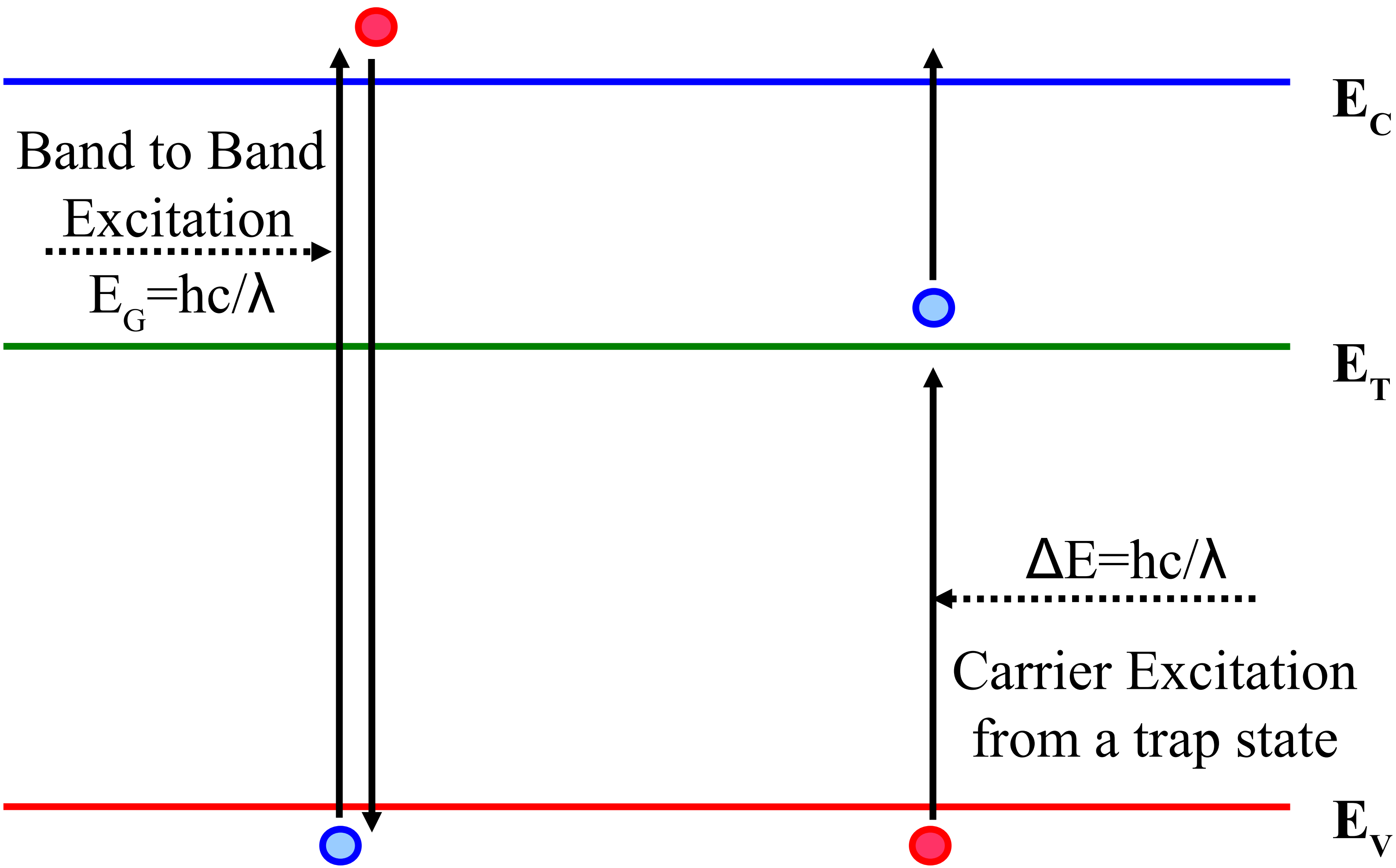
Some trap states arise from physical defects which are easy to identify via TEM, SEM, optical microscopy, etc.

Where can traps come from?

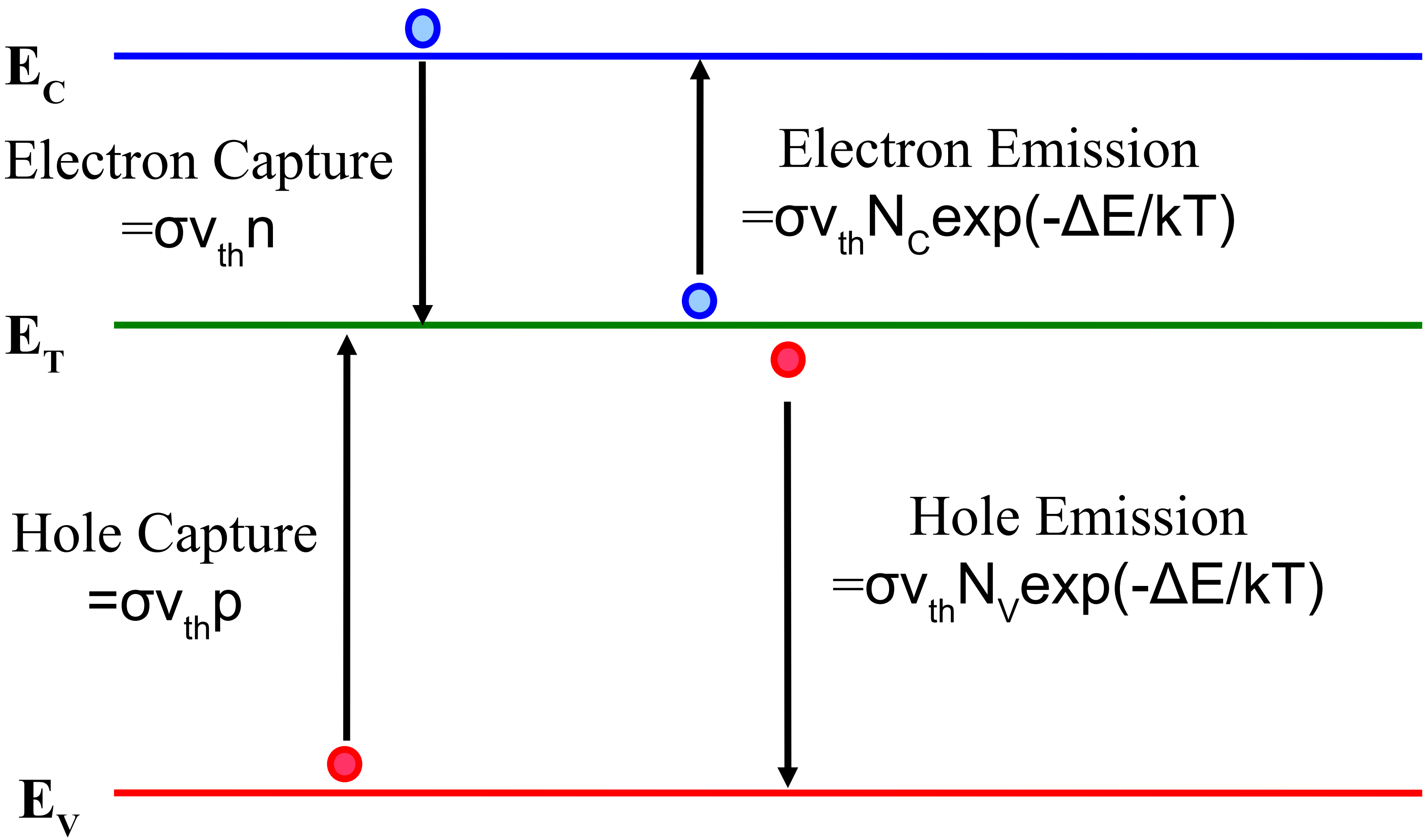


Other trap states arise from defects which are so small that they can't be "seen" except electrically. Nevertheless, both varieties of traps are important.

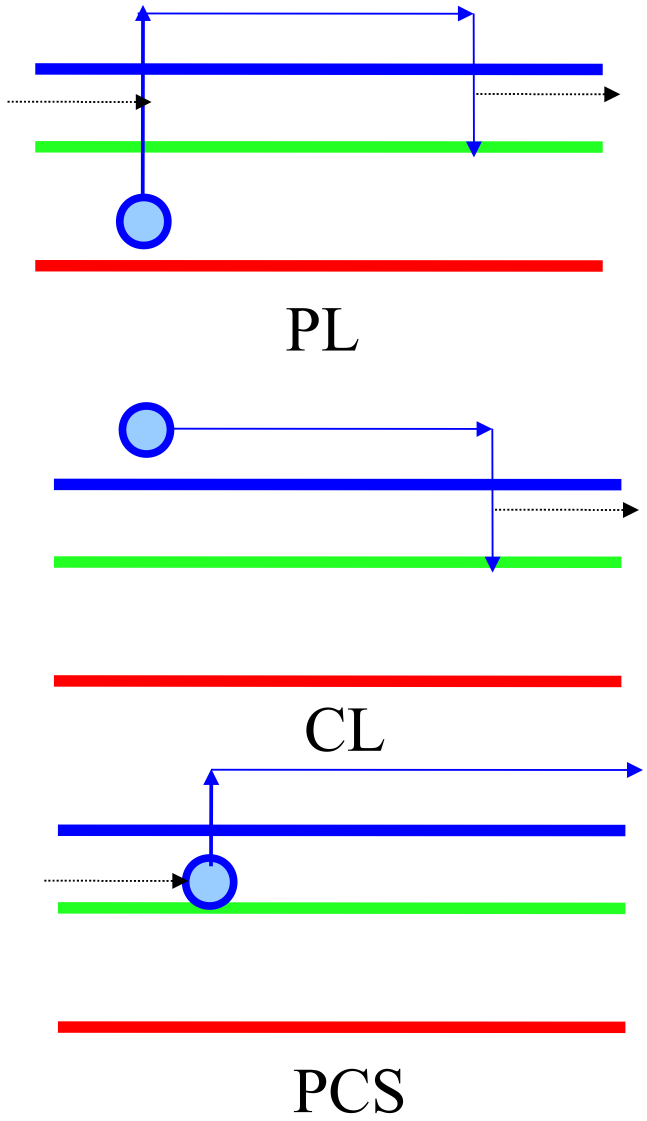
Free/Trapped Carrier Dynamics



Free/Trapped Carrier Dynamics

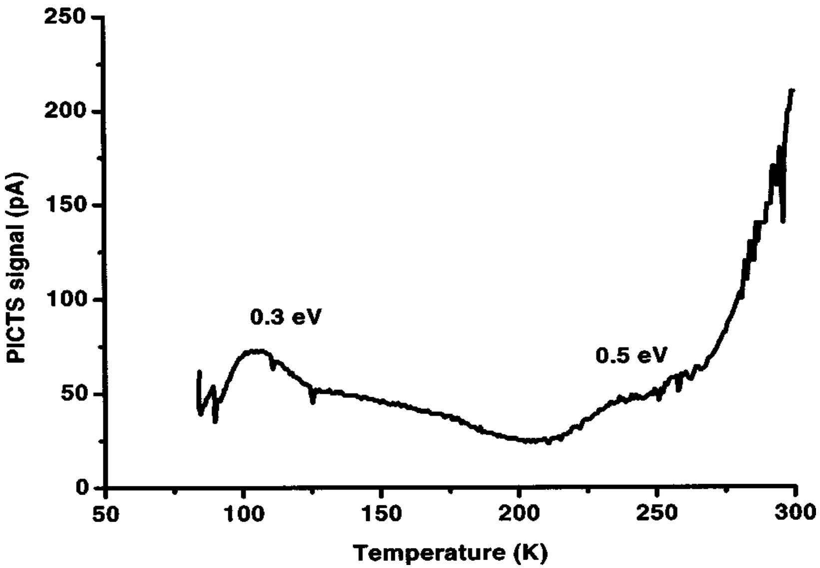


Existing Methods: PL, CL, PCS



- Advantages
  - Direct, light-based determination of trap densities with respect to energy.
  - Variable temperature is not required in order to determine the energy of trap levels.
- Disadvantages
  - Steady state measurement: no data is obtained with regards to rate of decay.
  - Carrier dynamics must be optically active to be observed.

Existing Methods: PL, CL, PCS

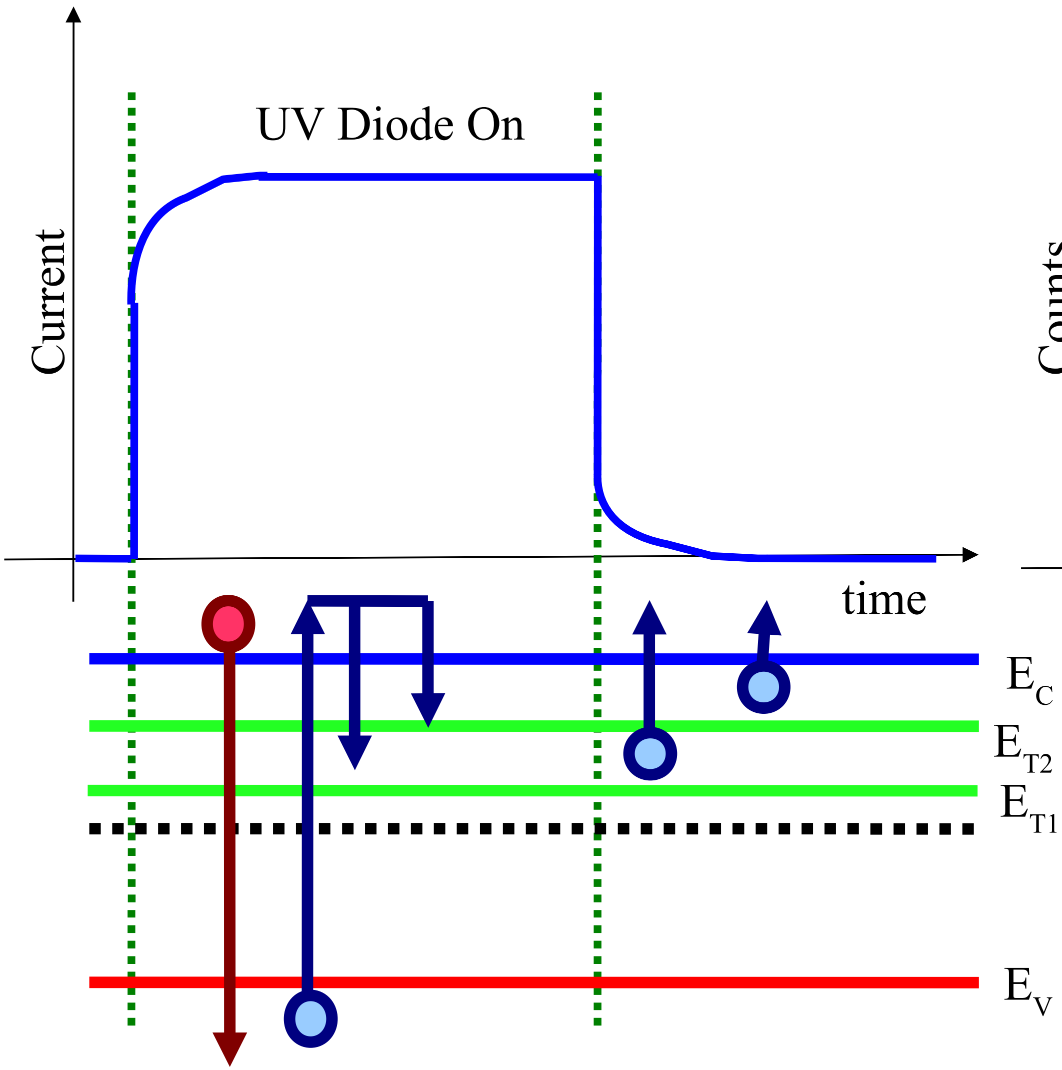


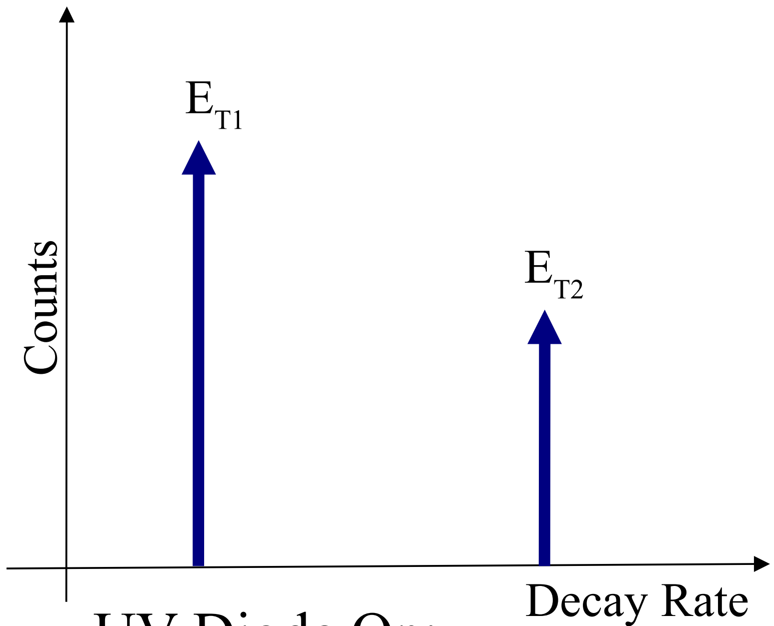
*Polyakov et. al., **J. Vac. Sci. Technol. B 18.3 (2000).**

- Advantages
  - Direct measurement of decay rates associated with carrier capture and emission of trapped carriers.

Disadvantages
  - Temperature scans are required in order for the technique to measure trap energy.
  - Temperature scans make the resolution of specific energies very difficult. It is also difficult to reproduce results.

Thermal Variance Method (DLTS)





UV Diode On:

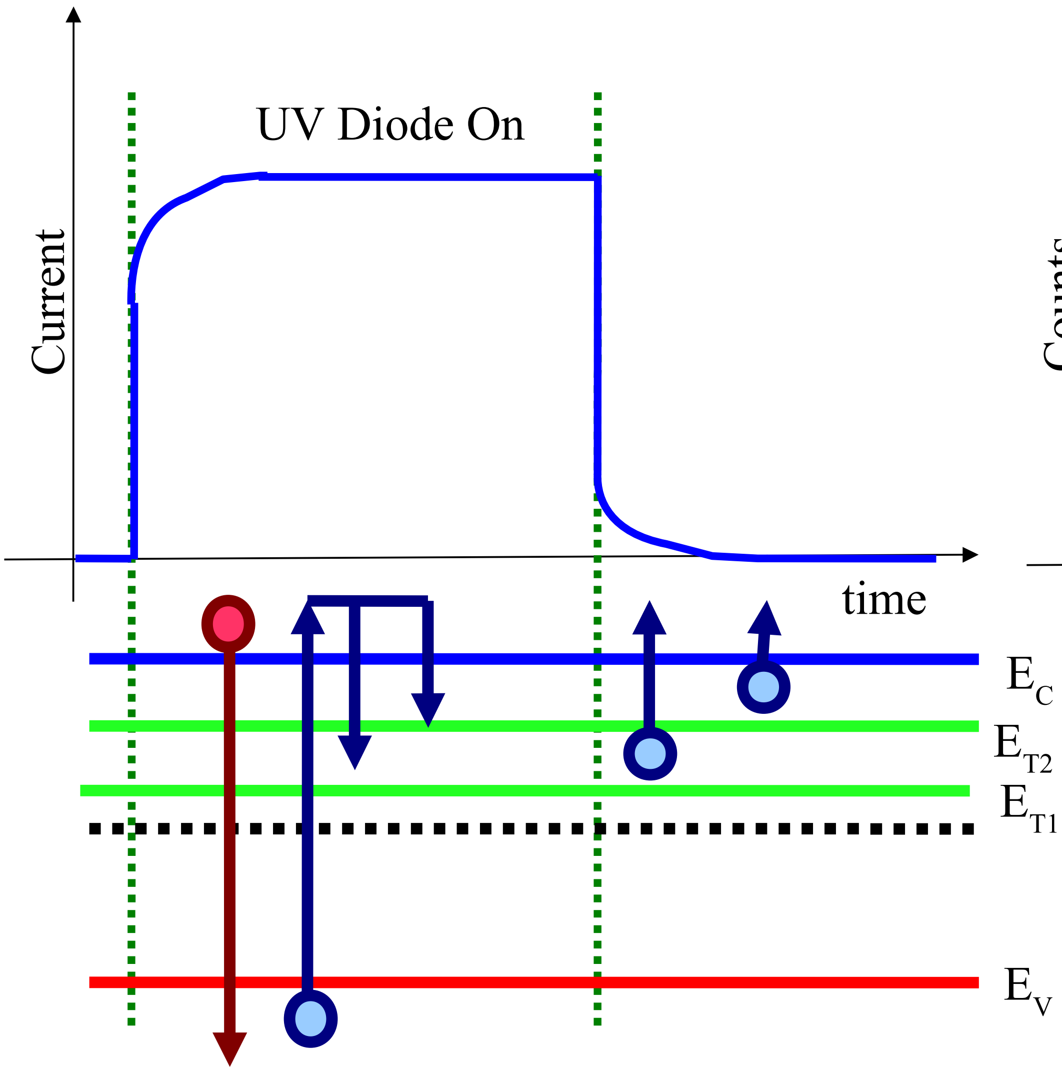
- Band to Band Excitation
- Free Carrier Capture

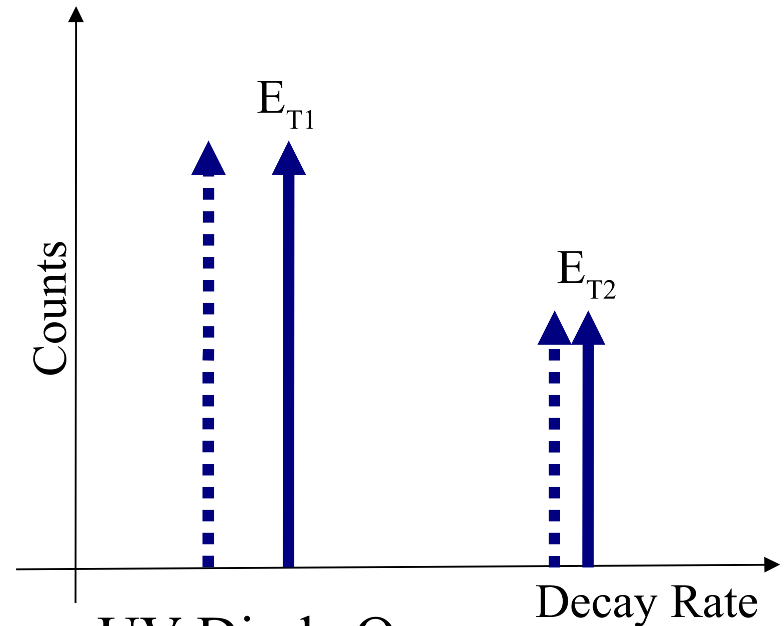
UV Diode Off:

- Trapped Carrier Emission

Temperature = 200K

Thermal Variance Method (DLTS)





UV Diode On:

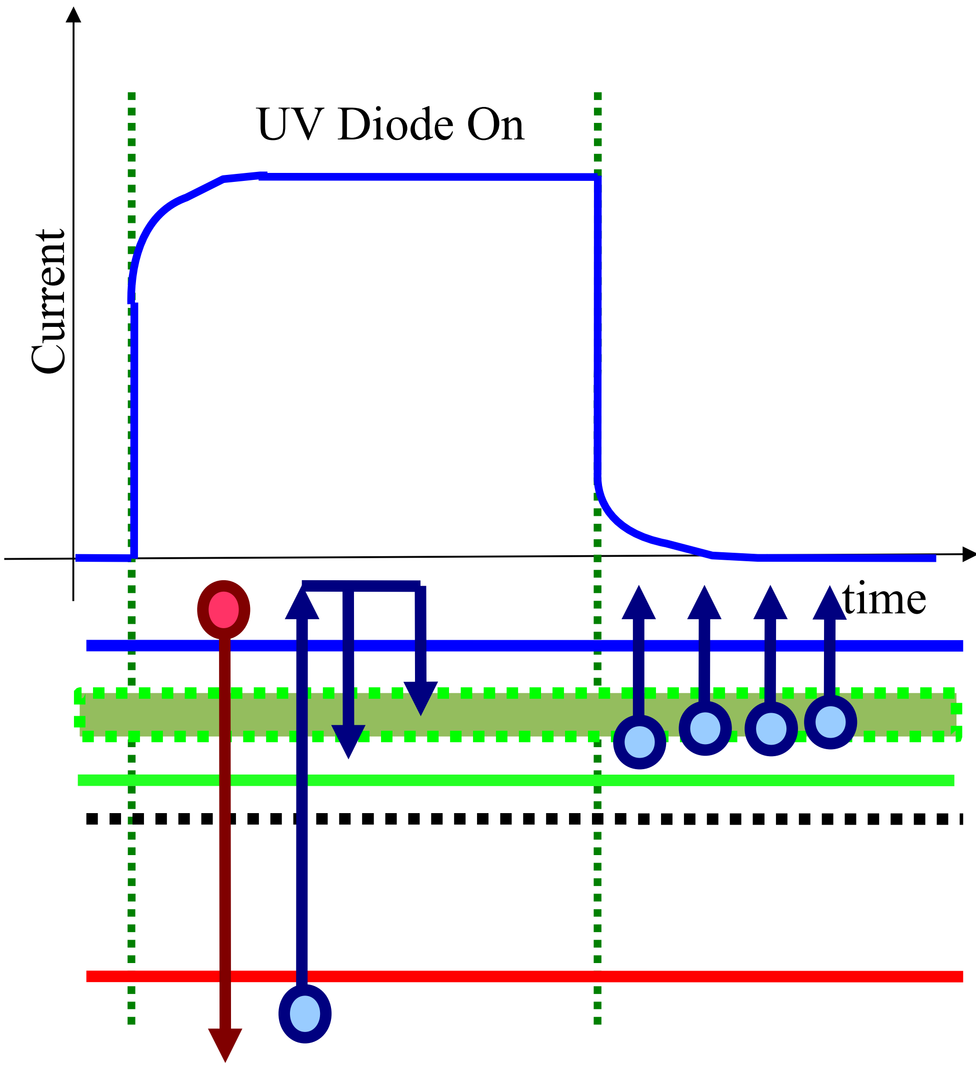
- Band to Band Excitation
- Free Carrier Capture

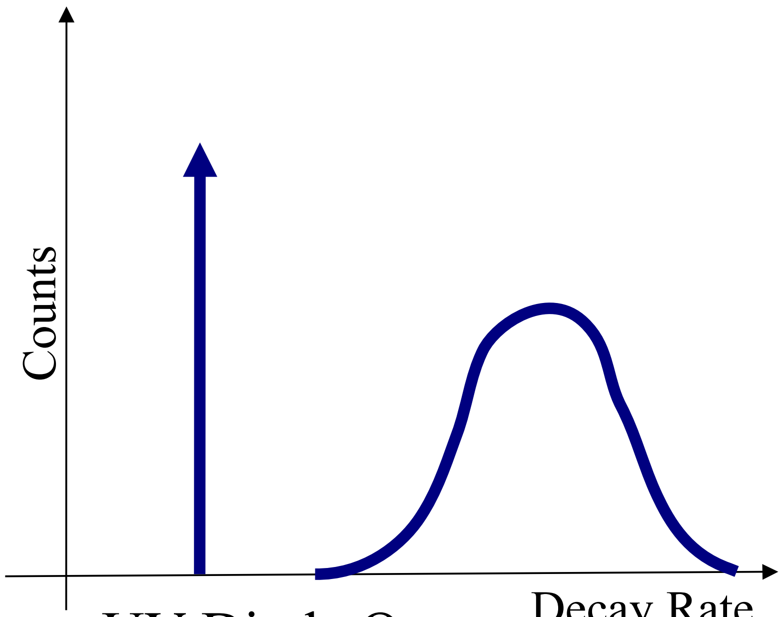
UV Diode Off:

- Trapped Carrier Emission

Temperature = 350K

Thermal Variance Method (DLTS)





UV Diode On:

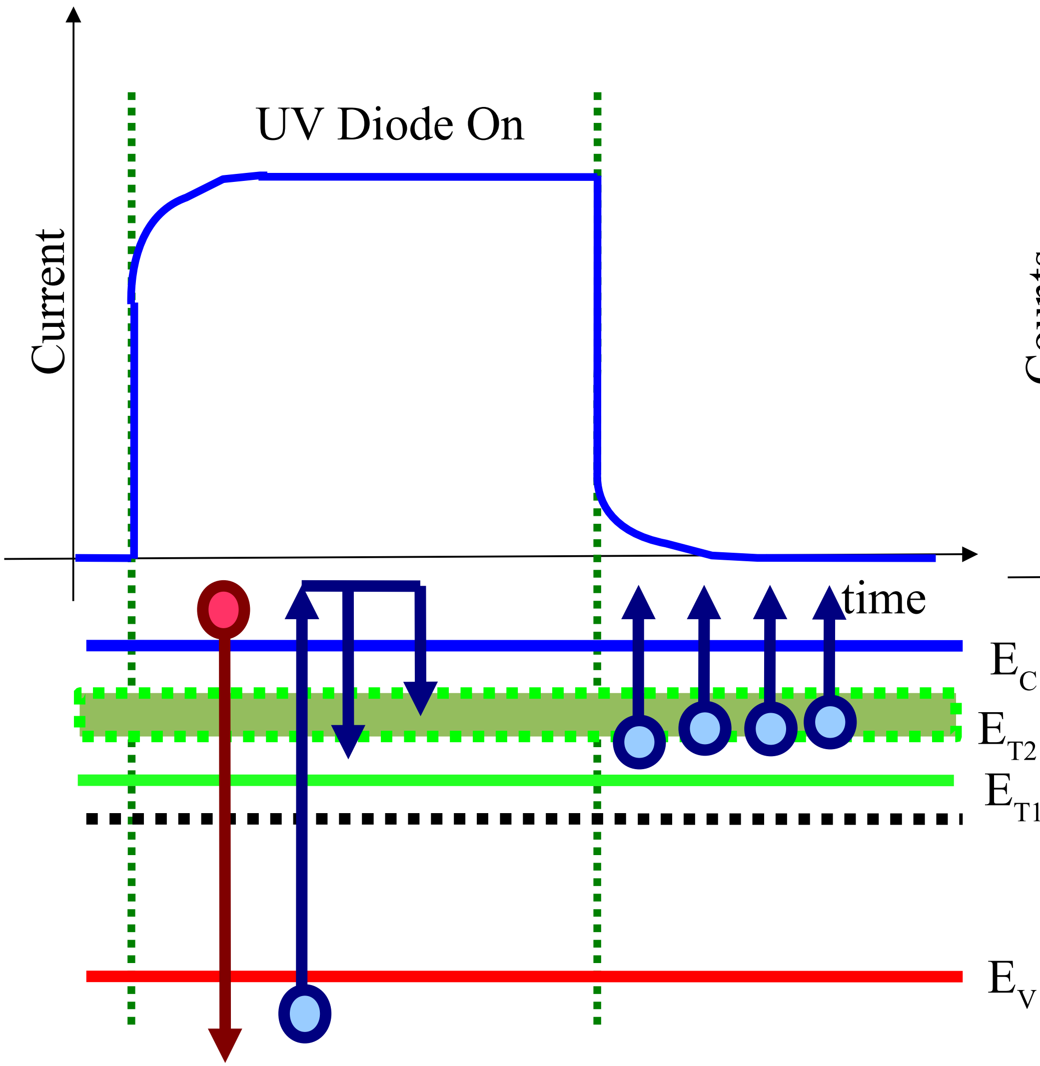
- Band to Band Excitation
- Free Carrier Capture

UV Diode Off:

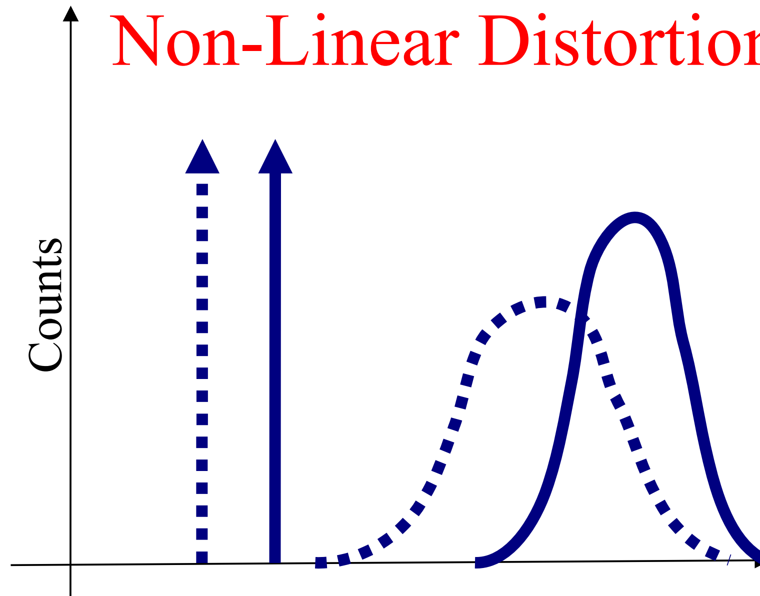
- Trapped Carrier Emission

Temperature = 200K

Thermal Variance Method (DLTS)



Non-Linear Distortion



UV Diode On:

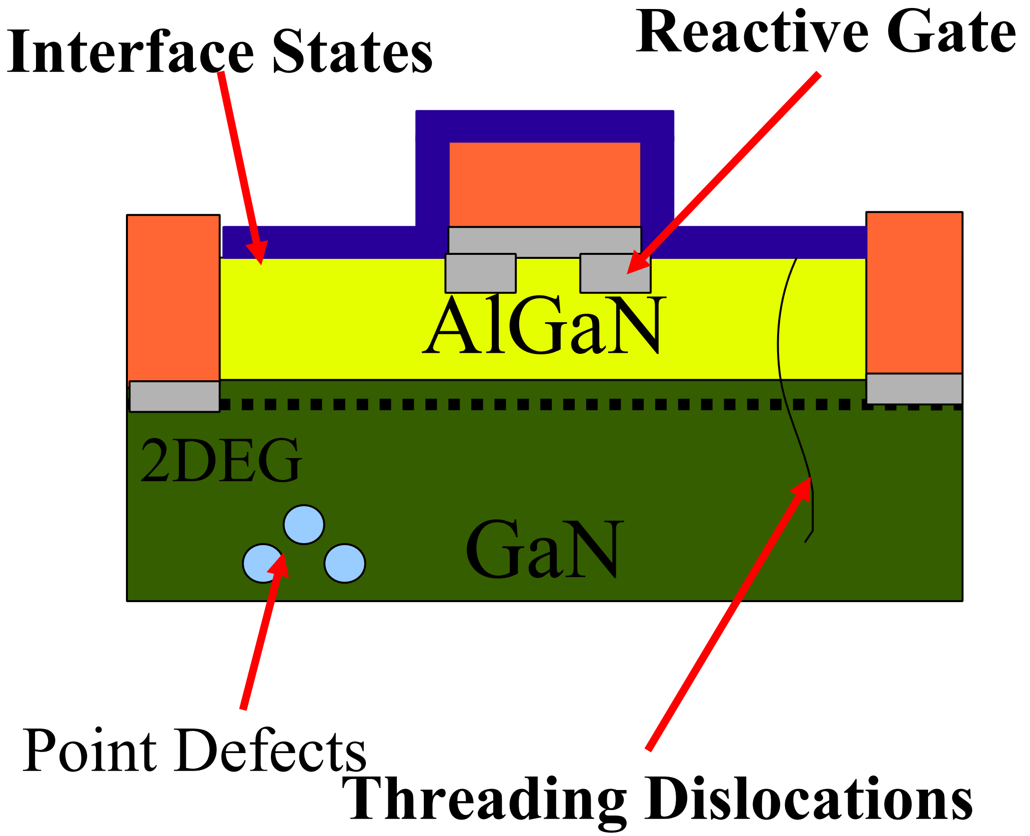
- Band to Band Excitation
- Free Carrier Capture

UV Diode Off:

- Trapped Carrier Emission

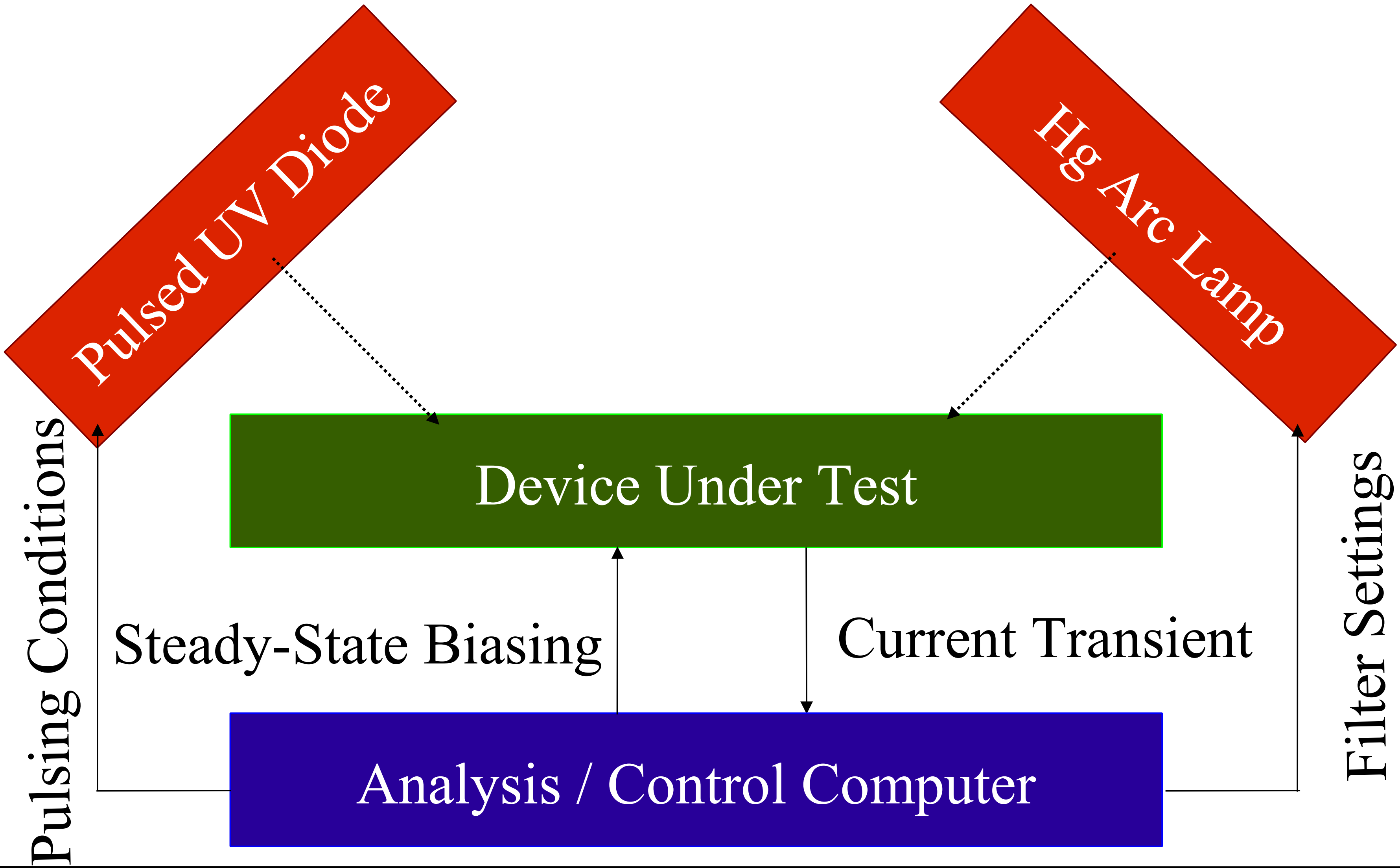
Temperature = 350K

Why DLTS won't work well for HEMTs

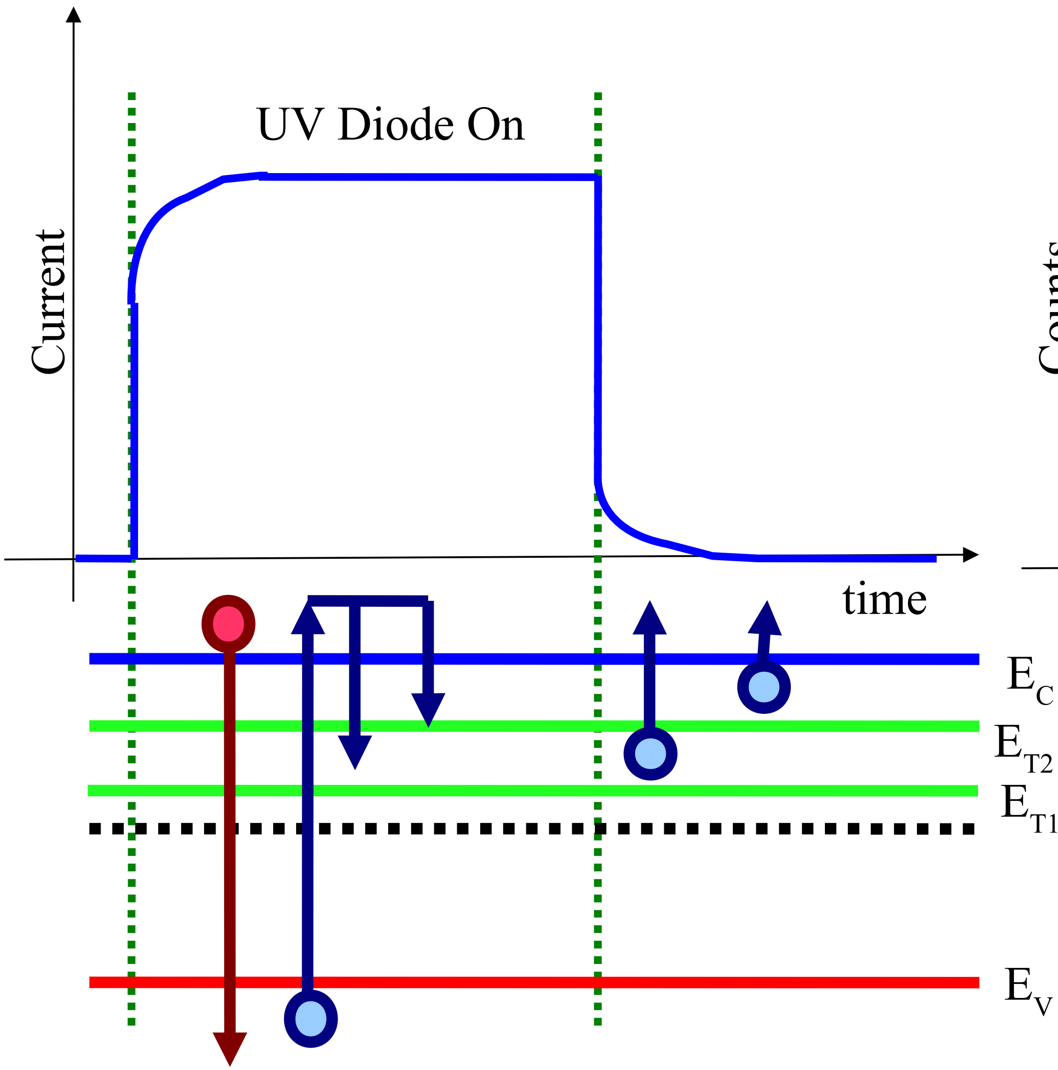


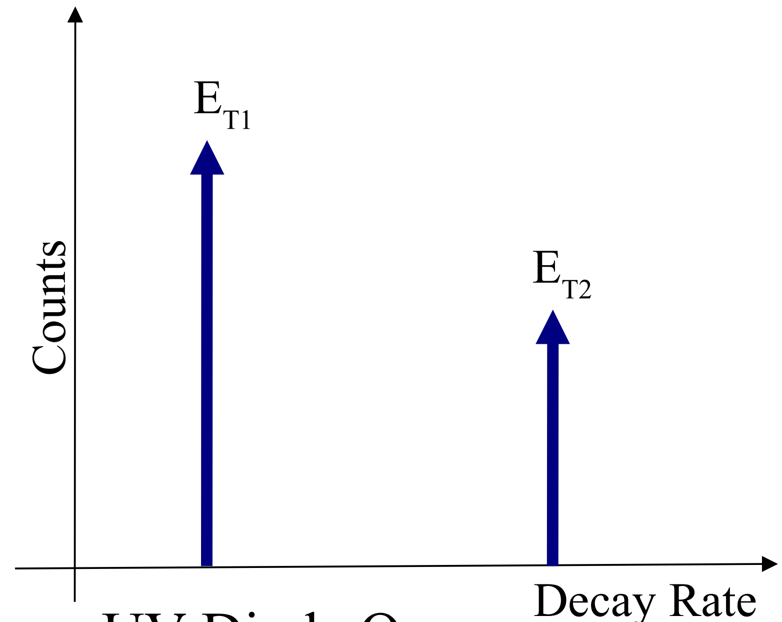
There are lots of defects which will yield an energy band of trap states within the forbidden gap!

The Solution: Take the Best of Both Worlds



Optical Scan Transient Spectroscopy (New!)





UV Diode On:

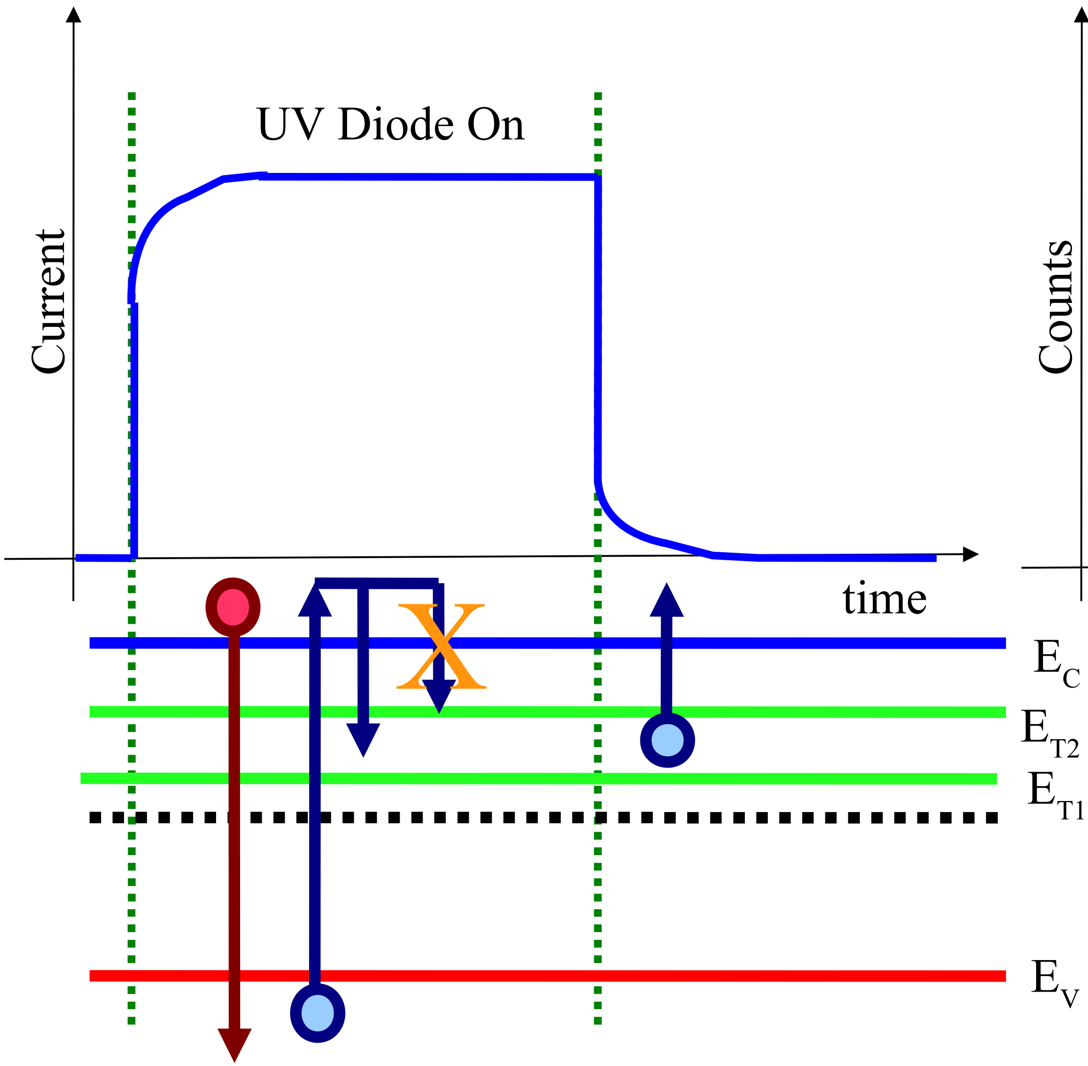
- Band to Band Excitation
- Free Carrier Capture

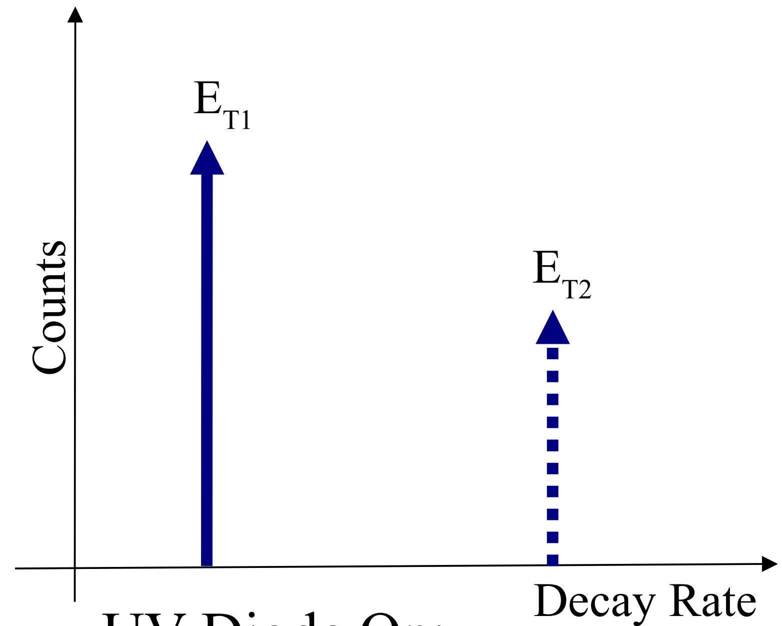
UV Diode Off:

- Trapped Carrier Emission

Secondary Light Source Off

Optical Scan Transient Spectroscopy (NEW!)





UV Diode On:

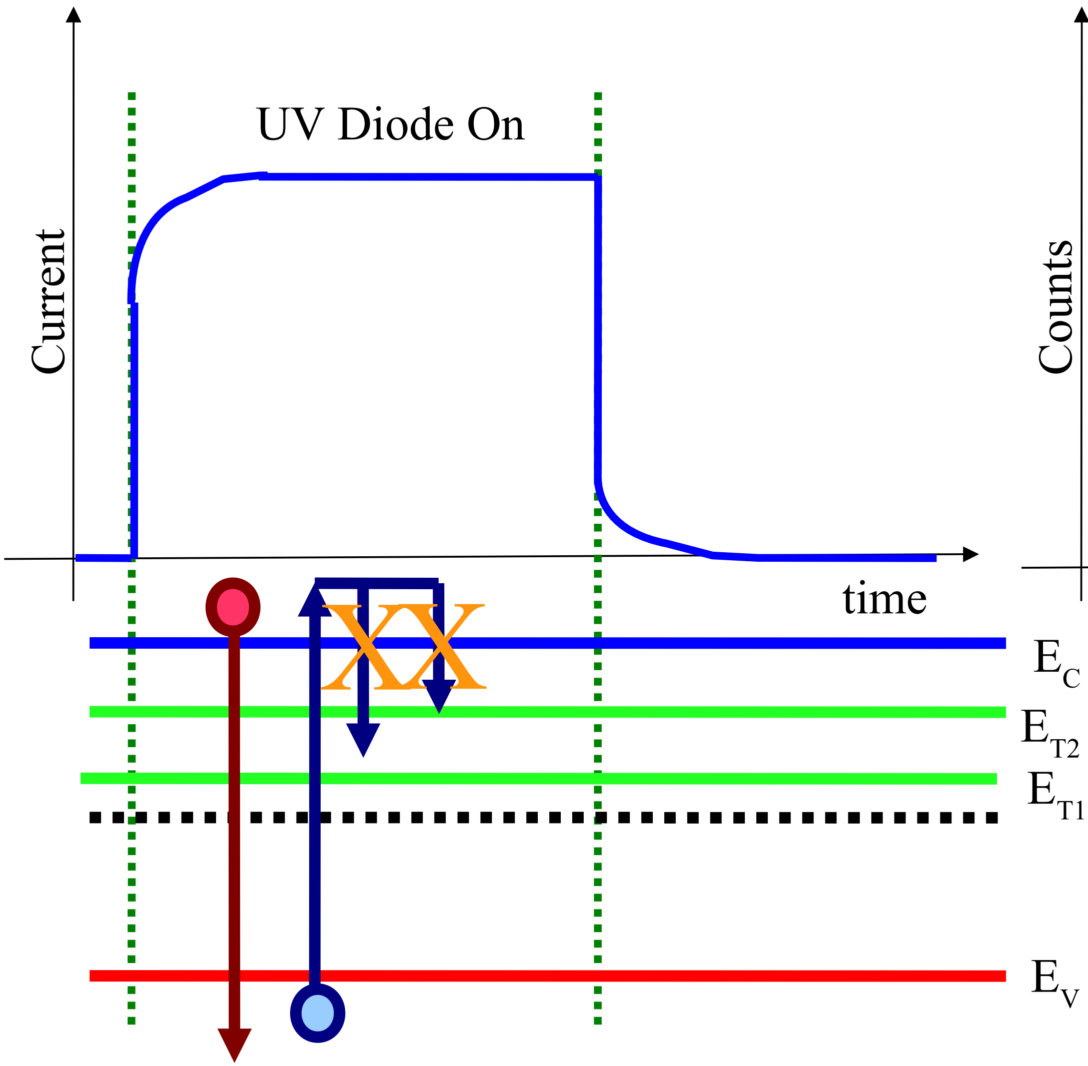
- Band to Band Excitation
- Free Carrier Capture

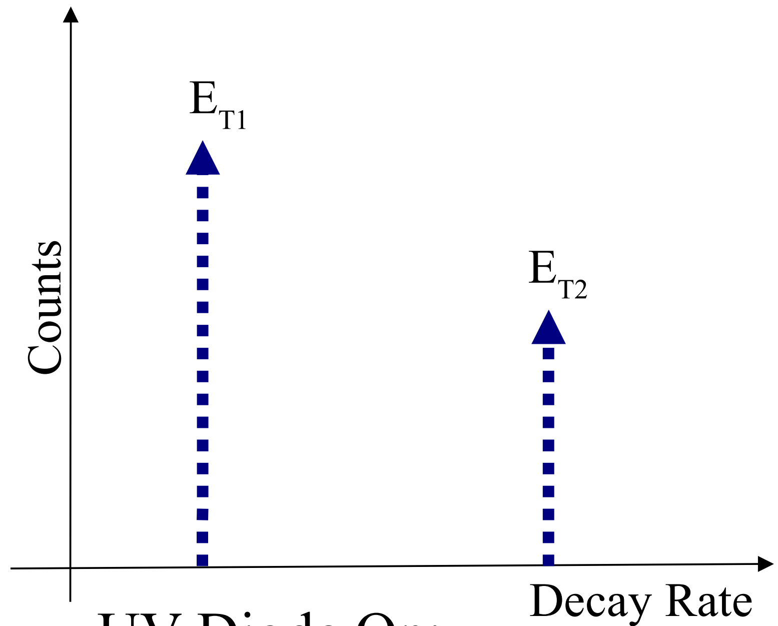
UV Diode Off:

- Emission from E_{T1} only

Secondary Light = E_{T2}

Optical Scan Transient Spectroscopy (NEW!)





UV Diode On:

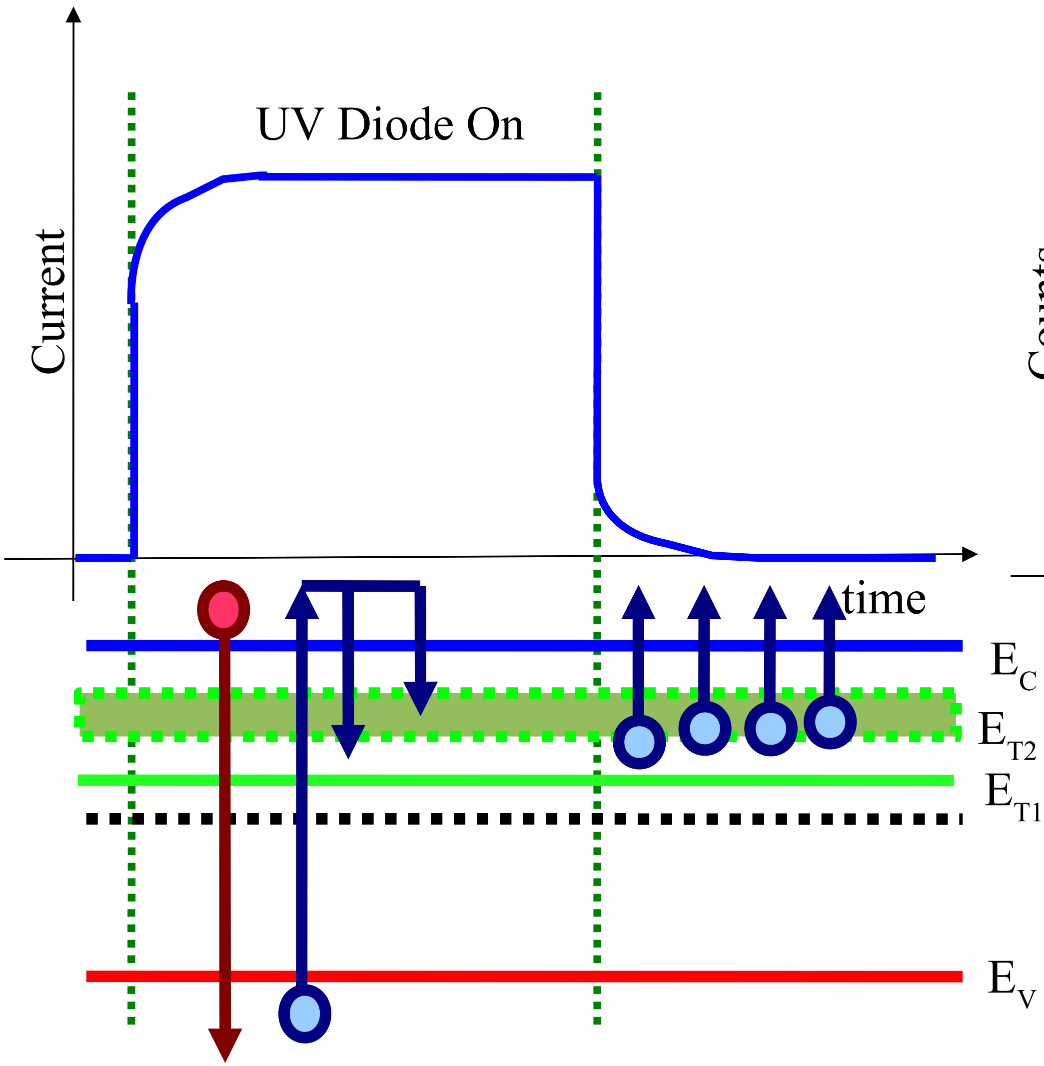
- Band to Band Excitation
- Free Carrier Capture

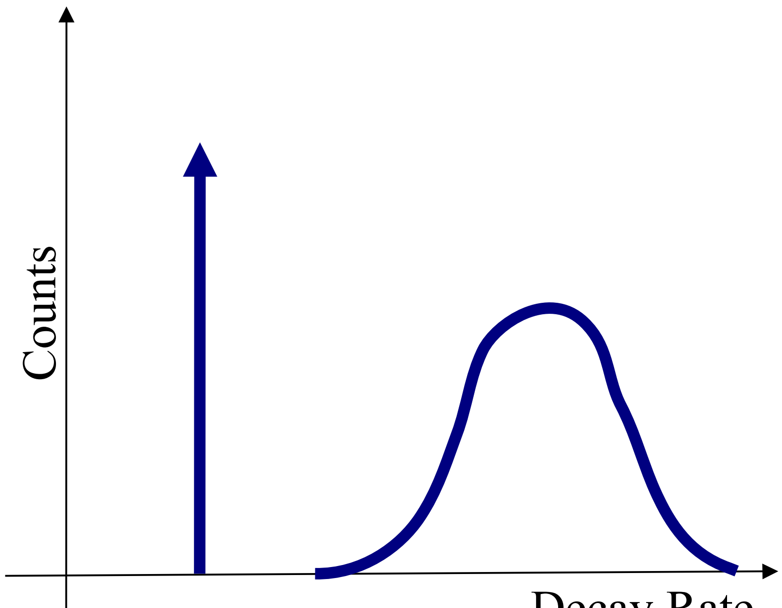
UV Diode Off:

- No Emission.

Secondary Light = E_{T1}

Optical Scan Transient Spectroscopy (NEW!)





UV Diode On:

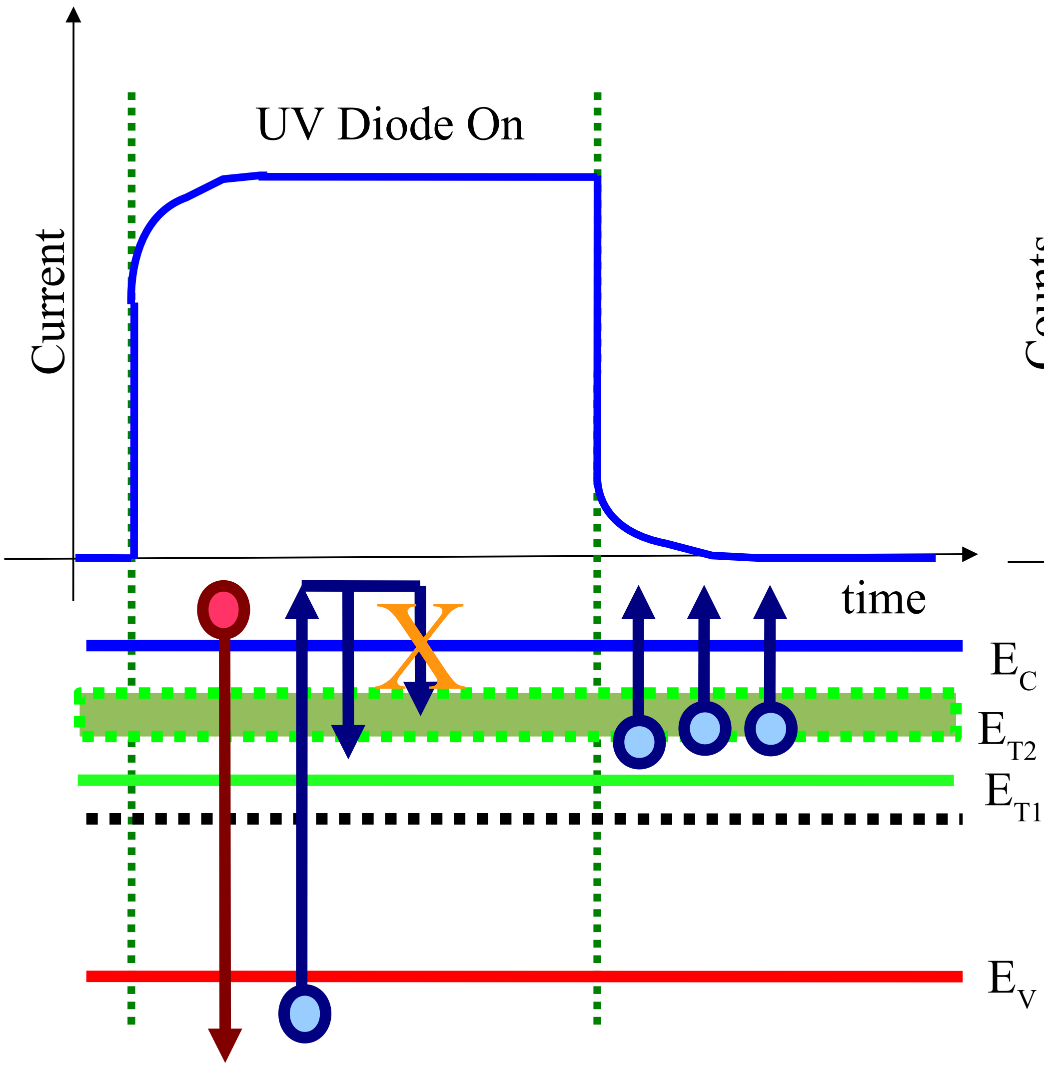
- Band to Band Excitation
- Free Carrier Capture

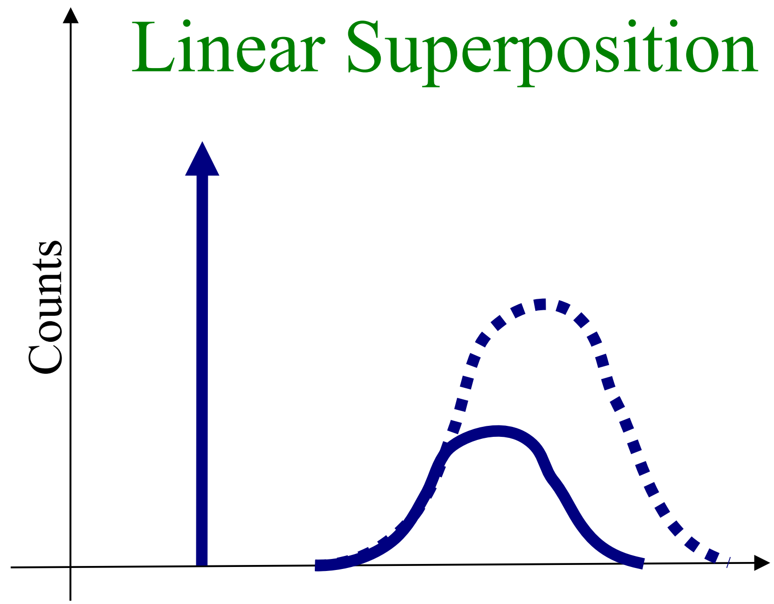
UV Diode Off:

- Trapped Carrier Emission

Secondary Light Source Off

Optical Pulsing Method (OSTS)





UV Diode On:

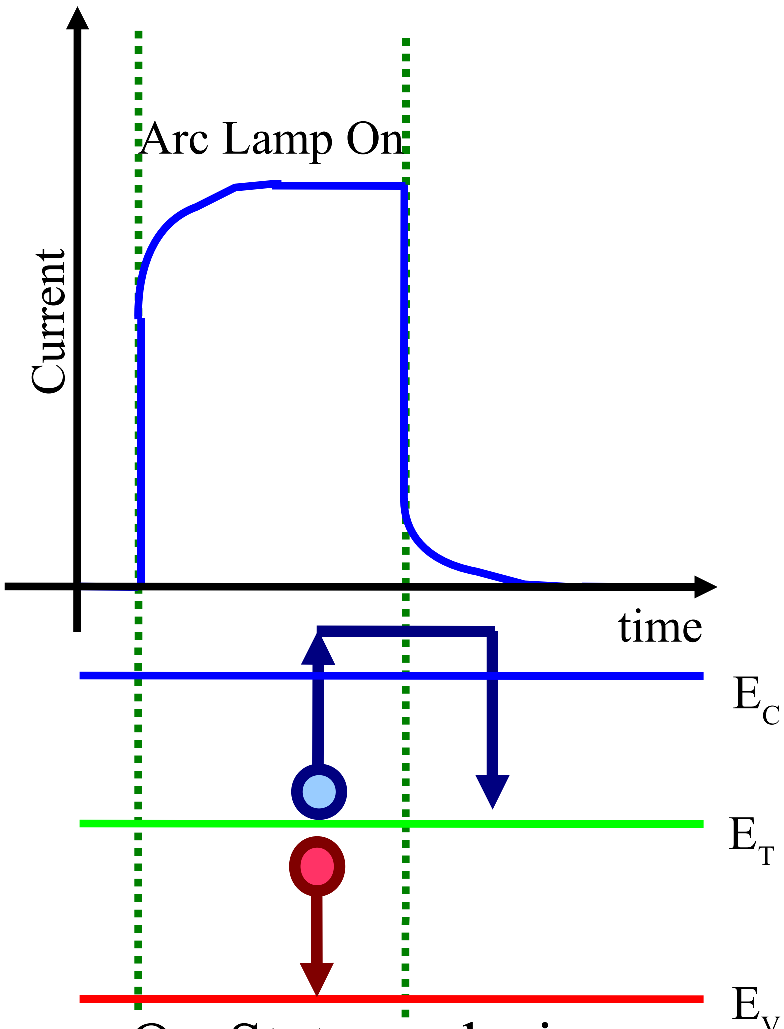
- Band to Band Excitation
- Free Carrier Capture

UV Diode Off:

- E_{T1}, Band edge emission

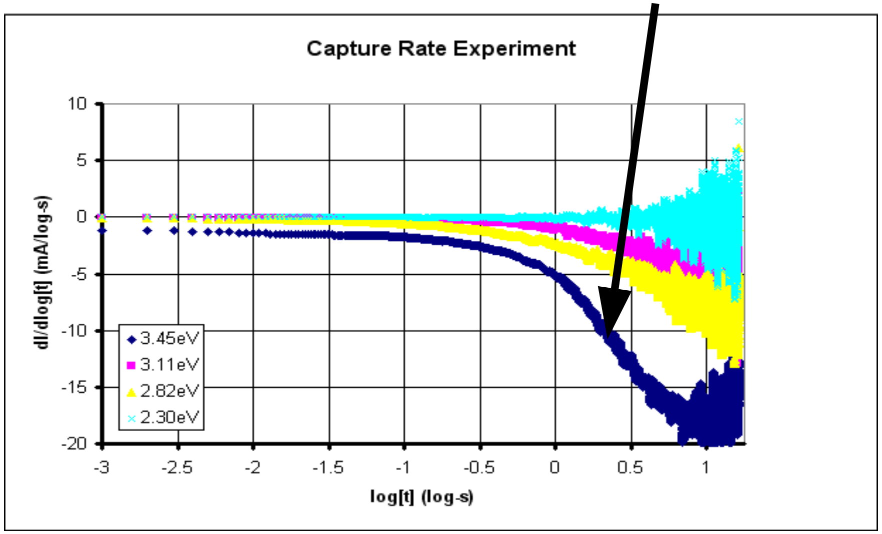
Secondary Light = E_{T2}

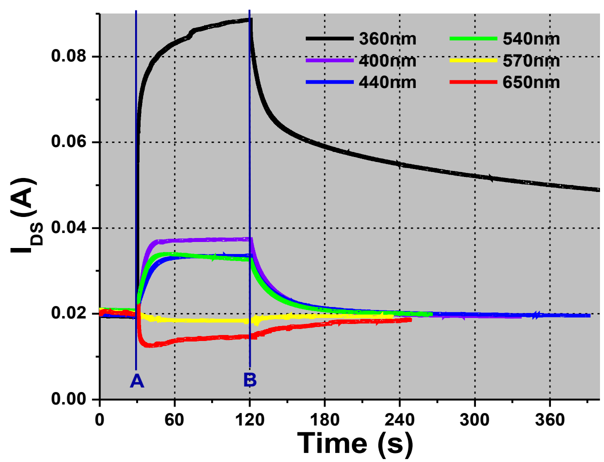
Example Experiment



On-State analysis

Emission Peak?

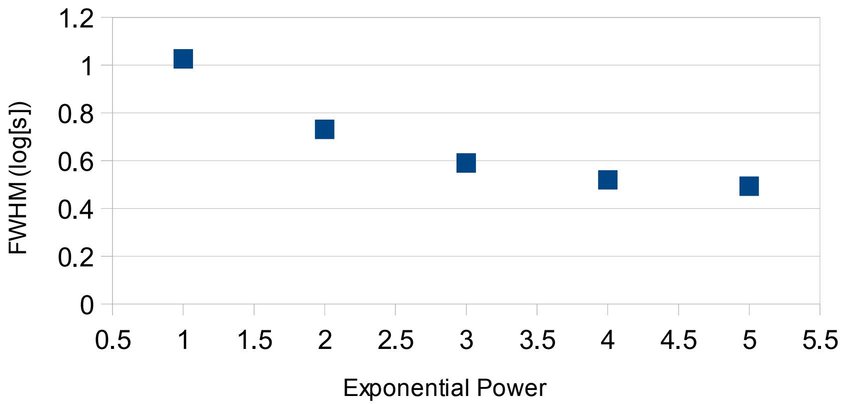


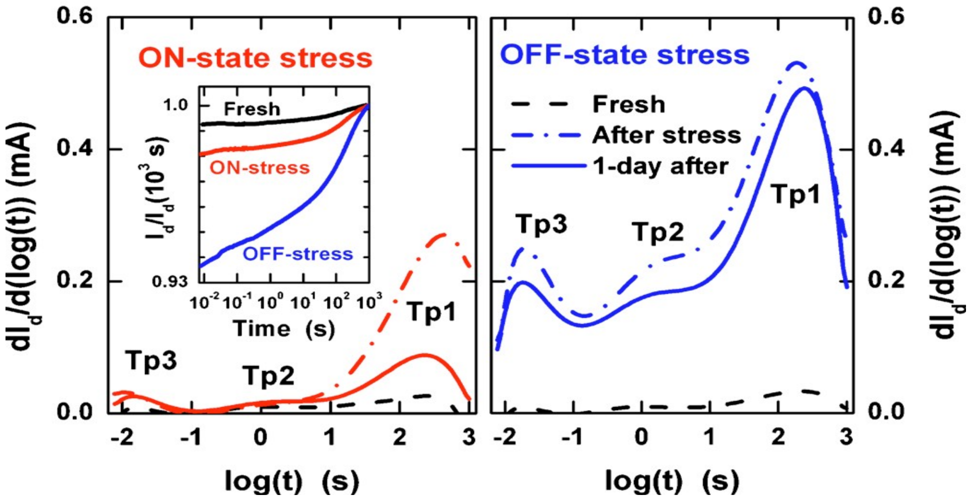


System Design: Minimum Decay Rates

- Data collection speed and rise/fall times for switching determine minimum decay rate.
  - 10us collection time for analog electronics which interface with the control computer
  - 10ns rise/fall time for the pulsed UV diode.
  - **Both shallow levels and deep levels can be resolved by OSTS.**

System Design: Decay Rate Resolution





*Tapajna et. al., Applied Physics Letters **97**, 023503 (2011)

- Algorithm choice is the determining factor in resolving two similar rates of decay.
  - dI/d(log[t]) vs log[t] is simple but has very poor resolution.
  - Resolution can be improved by squaring the differential.
  - Fast Laplace Transforms greatly improve decay rate resolution.

A Comparison*

Figure of Merit	OSTS	DLTS
Minimum Decay Rate	50 us	1ms
Decay Rate Resolution	<1 Order of Magnitude	>1 Order of Magnitude
Trap Energy Determination	Optical	Thermal
Trap Positioning	Optical Excitation	Variable Biasing

*Tapajna et. al., Applied Physics Letters **97**, 023503 (2011)

Conclusion

- A new method for observing trapping effects in AlGaN/GaN HEMTs, tentatively named Optical Scanning Transient Spectroscopy has been proposed.

- The OSTS system currently being developed at University of Florida has been described and an initial pulsed light experiment has been presented.

- Future work will include integration of a UV Diode into the OSTS system for UV excitation experiments, integration of a Fast Laplace Transform for improved spectral resolution and an initial “proof of concept” experiment.

Yearly Summary

- A new method for deprocesing AlGaN/GaN HEMTs has been developed. This new method shows promise as a means of sample preparation for plan-view imaging either via SEM or AFM.

- Work continues in building a system capable of detecting and analyzing the transient signal of deep level traps in HEMT structures. A new method for measuring these deep traps, Optical Scanning Transient Spectroscopy, has been proposed.

- Future work on stressed devices will focus both on further improvements to the deprocessing technique described, including integration with AFM, as well as the further development and experimental validation of OSTS.